
1000 वोल्ट तक एवं सहित की वोल्टता
रेटिंग हेतु स्वचालित पावर फैक्टर
कनेक्शन (APFC) पैनल

**Automatic Power Factor Correction
(APFC) Panels for Voltage Rating up
to and Including 1 000 V**

ICS 29.240.99

© BIS 2017



भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुरशाह ज़फर मार्ग, नई दिल्ली-110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI-110002
www.bis.org.in www.standardsbis.in

Foreword

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Power Capacitors Sectional Committee has been approved by the Electrotechnical Division Council.

Low Voltage (LV) Automatic Power Factor Correcting (APFC) panels are installed in distribution lines for improvement of power factor correction. The important advantages of APFC panels over fixed capacitor banks are (1) Ability to maintain Power Factor (PF) at the target value, closer to unity and hence avoid penalties imposed by electricity supply companies due to low PF, (2) Avoid over compensation during low load conditions and (3) Improved efficiency of the system.

This standard has been prepared with a view to formulate the safety, performance requirements and methods of tests for LV APFC panels connected in parallel to an electrical equipment or a power system for the purpose of power factor improvement. This standard also provides guidance for design, Installation, operation and safety of such LV APFC panels.

In preparing this standard considerable assistance has been derived from IEC 61921 : 2003, “Power Capacitors — low voltage power factor correction banks” and IEC 61439-1 : 2011, “Low voltage switchgear and control-gear assemblies, Part 1: General rules”.

For the purpose of deciding whether a particular requirement of this Standard is complied with, the final value, observed or calculated expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 “Rules for rounding of numerical values (*revised*)”. The number of significant places retained in the rounded off value should be the same as that of the specified value in this Standard.

Indian Standard

AUTOMATIC POWER FACTOR CORRECTION (APFC) PANELS FOR VOLTAGE RATING UP TO AND INCLUDING 1 000 V

1 SCOPE

This Indian Standard is applicable to low voltage a.c. Automatic Power Factor Correction (APFC) panels intended to be used for automatic power factor correction purposes, equipped with capacitor banks and switching device (s) (either electro-mechanical or electronic) and other components with the aim to correct the power factor to the target value.

The constituent components of the panel like capacitors, switching devices, instrument transformers, fuses, damping and de-tuning reactors, current limiting devices, control and auxiliary circuits, supporting insulators, accessories, busbars, cables, etc., shall be in accordance with relevant Indian Standards.

2 REFERENCES

The following standards contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication of this standard, the edition indicated are valid. All standards are subject to revision.

*Indian Standard**Title*

IS 694:2010/IEC 60227	PVC Insulated cables for working voltages up to and including 1100 V
IS 1885 (all parts)	Electro-technical vocabulary
IS 2071 (Part 1): 1993/ IEC 60060-1	High voltage test techniques: Part 1 General definitions and test requirements
IS 2705 (all parts): 1992	Current transformers
IS 3156 (all parts): 1992	Voltage transformers
IS 5553 (all parts)	Reactors
IS 7098 (Part 1): 1998	Cross-linked polyethylene insulated PVC sheathed cables: Part 1 For working voltage up to and including 1100 V
IS 8623 (Part 1): 1993/ IEC 60439-1	Low-voltage switchgear and controlgear assemblies: Part 1 Type-tested and partially type-tested assemblies
IS 8623 (Part 3): 1993/ IEC 60439-3	Low-voltage switchgear and controlgear assemblies: Part 3 Particular requirements for low-voltage switchgear and

*Indian Standard**Title*

	controlgear assemblies intended to be installed in places where unskilled persons have access for their use — Distribution boards
IS 11298 (Part 3/Sec 1): 1991	Plastic films for electrical purposes: Part 3 Specifications for individual materials, Section 1 Polypropylene film for capacitors
IS 12360: 1988	Voltage Bands for Electrical Installations Including Preferred Voltages and Frequency
IS 12672: 1989/ IEC 60593	Internal fuses and internal overpressure disconnectors for shunt capacitors
IS 13067: 1991	Impregnants for power capacitors
IS 13340 (Part 1): 2012/ IEC 60831-1	Shunt power capacitors of the self-healing type for a.c. systems having a rated voltage up to and including 1000 V: Part 1 General — Performance, testing and rating — Safety requirements — Guide for installation and operation
IS 13340 (Part 2): 2012/ IEC 60831-2	Requirements for ageing test, self-healing test and destruction test on shunt capacitors of the self-healing type for ac power systems having a rated voltage up to and including 1000 V
IS 13585 (Part 1): 2012/ IEC 60931-1	Shunt power capacitors of the non-self-healing type for a.c. systems having a rated voltage up to and including 1 000 V : Part 1 General — Performance, testing and rating — Safety requirements — Guide for installation and operation
IS 13703 (all parts)	Specification for Low-Voltage Fuses for Voltages not exceeding 1000 V AC or 1500 V DC

<i>Indian Standard</i>	<i>Title</i>
IS/IEC 60529:2001	Classification of degrees of protection provided by enclosures of electrical equipment
IS/IEC 60947 (all parts)	Specification for Low-voltage Switchgear and Controlgear

3 TERMINOLOGIES

For the purpose of this document, in addition to the definitions given in IS 8623-1/IEC 61439-1, IS 13340/IEC 60831 and IS 13585/IEC 60931 following shall apply.

3.1 Low Voltage Automatic Power Factor Control/Correction (APFC) Panel

Combination of one or more capacitor units together with associated devices for switching, controlling, measuring, signalling, protection, regulation, etc., assembled together for providing automatic correction to the power factor (PF) to the target value with the help of automatic reactive power controller/regulator.

NOTE — The target value for PF correction is to be decided between the purchaser and the manufacturer, depending on the application.

For the purpose of this standard, “APFC Panel” will be termed as “Panel”.

3.2 Automatic Power Factor Controller

Device designed to sense power factor of the load connected to the power line and to control the switching on and off of the steps of the capacitor bank, in order to correct the power factor to the target value.

NOTE— The components of automatic PF controller / regulator of APFC panel may be electro-mechanical or electronic.

3.3 Automatic Reactive Power Controller/Regulator (RPC)

Device designed to calculate the reactive power absorbed by the load connected to the power line and to control the switching on and off of the steps of the automatic bank, in order to compensate for the reactive power

NOTES

- 1 The reactive power is normally calculated at the fundamental frequency.
- 2 The controller may be “built-in” or “free-standing” and has usually to be adjusted for each bank before operation.

3.4 Response Time (T_{cr}) of Automatic Power Factor Control Panel

Response time of APFC panel for PF correction is the interval of time between the instant of sensing the prevailing power factor and the instant of correcting to the target power factor.

3.5 Low Voltage A.C. Capacitor Bank

Combination of one or more capacitor units together with associated devices for switching, controlling, measuring, signalling, protection, regulation, etc., completely assembled under the responsibility of the manufacturer with all the internal electrical and mechanical inter connections and structural parts.

3.6 Step of Capacitor Bank

Combination of one or more capacitor units switched together.

3.7 Main Circuit

All the conductive parts of a panel (or an assembly) included in a circuit which are intended to compensate the reactive power from which one or several branch circuits can be connected.

3.8 Branch Circuit

A circuit which connects one step of capacitor bank to the main circuit.

NOTE — A panel may have one or more branch circuits.

3.9 Control and Auxiliary Circuit

All conductive parts of a panel (or an assembly) included in a circuit (other than the main circuit) intended to control, measure, signal, regulate, process data, etc.

NOTE— The auxiliary circuits of a panel include the control and the auxiliary circuits of the switching devices.

3.10 Functional Unit

A part of a panel comprising of all the electrical and mechanical elements those contribute to the fulfilment of the same function.

NOTE — Conductors which are connected to a functional unit but which are external to its compartment or enclosed protected space (e.g. auxiliary cables connected to a common compartment) are not considered to form part of the functional unit.

3.11 Functional Group

A group of several functional units which are electrically interconnected for the fulfilment of their operational functions.

3.12 Switching Device

Device designed to make or break the current in one or more electric circuits.

NOTE — A switching device may perform one or both of these operations.

3.13 Mechanical Switching Device

Switching device designed to close and open one or more electric circuits by means of separable contacts.

3.14 Electronic Switching Device

Switching device designed to close and open one or more electric circuits by means of controlled conductivity of a semiconducting device.

3.15 Interlocking Device

Device which makes the operation of a switching device dependent upon the position of operation of one or more other pieces of equipment.

3.16 With-Drawable Part

Removable part which can be moved from the connected position to the isolated position and to a test position, if any, whilst remaining mechanically attached to the panel.

3.17 Incoming Unit

A functional unit through which electrical energy is normally fed into the panel.

3.18 Outgoing Unit

A functional unit through which electrical energy is normally supplied to one or more outgoing circuits.

3.19 Cable Entry

A part with openings which permit the passage of cables into the panel.

NOTE— A cable entry can at the same time be designed as a cable sealing end.

3.20 Enclosure

Housing of the panel, capable of providing the type and degree of protection suitable for the intended application.

3.21 Cover

A part of the external enclosure of a panel.

3.22 Panel for Indoor Installation

A panel which is designed for use in locations where the normal service conditions for indoor use as specified in 7.1 of this standard are fulfilled.

3.23 Panel for Outdoor Installation

A panel which is designed for use under the normal service conditions for outdoor use as specified in 7.1 of this standard

3.24 Pollution

Any condition of foreign matter, solid, liquid or gaseous (ionized gases) that may affect dielectric strength or surface resistivity

3.25 Pollution Degree (of Environmental Conditions)

Conventional number based on the amount of conductive or hygroscopic dust, ionized gas or salt, and on the relative humidity and its frequency of occurrence resulting in hygroscopic absorption or condensation of moisture leading to reduction in dielectric strength and/or surface resistivity

NOTES

1 The pollution degree to which the insulating materials of devices and components are exposed may be different from that of the macro-environment where the devices or components are located because of protection offered by means such as an enclosure or internal heating to prevent absorption or condensation of moisture.

2 For the purpose of this standard, the pollution degree is of the micro-environment.

3.26 Manufacturer

For the purposes of this standard, manufacturer is a person or a company or an organisation with ultimate responsibility to:

- a) provide the panel so as to comply with the appropriate standard or standards
- b) provide the panel information according to 4

3.27 Protective Measures with Regard to Electric Shock

3.27.1 Live Part

A conductor or conductive part intended to be energized in normal use, including a neutral conductor.

NOTE — This term does not necessarily imply a risk of electric shock.

3.27.2 Live Terminal

Point of interconnection of the panel with other electric circuit elements, electric circuits or networks.

NOTE — For an electric circuit element, the terminals are the points at which or between which the related integral quantities are defined. At each terminal, there is only one electric current from outside into the element.

3.27.3 Conductive Part

Part which is capable of conducting current.

3.27.4 Exposed Conductive Part

A conductive part of electrical equipment, which can be touched and which is not normally live, but which may become live under fault conditions

NOTE— Typical exposed conductive parts are walls of enclosures, operating handles, etc.

3.27.5 Protective Conductor

Conductor provided for purposes of safety, for example protection against electric shock

NOTE — As an example, the protective conductor can electrically connect the following parts:

1. exposed conductive parts;
2. extraneous conductive parts;
3. main earthing terminal;
4. earth electrode;
5. earthed point of the source or artificial neutral.

3.27.6 Surge Arrester; Surge Protective Device (SPD)

Device designed to protect the electrical apparatus from high transient over voltages and to limit the duration and amplitude of the follow-on current

3.27.7 Electric Shock

Pathophysiological effect resulting from an electric current passing through a human or animal body

3.28 Electrical Characteristics of APFC Panels

3.28.1 Rated Voltage of the Panel (U_N)

The highest nominal value of the a.c. (r.m.s.) voltage declared by the manufacturer, to which the main circuit(s) of the panel is (are) designed to be connected.

NOTES

- 1 In poly-phase circuits, it is the voltage between phases.
- 2 Transients are disregarded.
- 3 The value of the supply voltage may exceed the rated voltage due to permissible system tolerances.

3.28.2 Rated Insulation Voltage (U_i)

r.m.s withstand voltage value, assigned by the manufacturer to the equipment or to a part of it, characterizing the specified (long-term) withstand capability of the insulation.

NOTES

- 1 In polyphase circuits, it is the voltage between phases.
- 2 The rated insulation voltage is not necessarily equal to the rated operational voltage of equipment which is primarily related to functional performance.
- 3 It is the value to which dielectric test voltages and creepage distances are referred.

3.28.3 Rated Operational Voltage (U_o)

The value of voltage, declared by the manufacturer, which combined with the rated current, determines its application.

NOTE— In polyphase circuits, it is the voltage between phases.

3.28.4 Power-Frequency Withstand Voltage

r.m.s. value of a power-frequency sinusoidal voltage which does not cause breakdown under specified conditions of test

3.28.5 Rated Impulse Withstand Voltage (U_{imp})

The peak value of an impulse voltage of prescribed form and polarity which the circuit of a panel is capable of withstanding without failure under the specified conditions of test and to which the values of the clearances are referred.

The rated impulse withstand voltage of a circuit of a panel shall be equal to or higher than the values stated for the transient over voltages occurring in the system in which the panel is inserted.

NOTE — The preferred values of rated impulse withstand voltage are those given in Table 4.

3.28.6 Overvoltage

Any voltage having a peak value exceeding the corresponding peak value of the maximum steady-state voltage at normal operating conditions

3.28.7 Transient Overvoltage

Short duration overvoltage of a few milliseconds or less, oscillatory or non- oscillatory, usually highly damped

3.28.8 Rated Current (I_n)

The rated current is stated by the manufacturer, taking into consideration the ratings of the components of the electrical equipment within the panel, their disposition and application. Rated current is derived from rated power and rated voltage of the panel.

3.28.9 Transient Inrush Current (I_i)

Transient inrush or overcurrent occurs when a capacitor is switched on. Amplitude and frequency of transient inrush current are determined by the factors such as the short circuit impedance of the supply, the amount of energized capacitance switched in parallel, the instant of the switching, series reactors, type of switch, etc.

3.28.10 Rated Peak Withstand Current (I_{pk})

Value of peak short-circuit current, declared by the manufacturer, that can be withstood under specified conditions

3.28.11 Rated Short-Time Withstand Current (I_{cw})

r.m.s value of short-time current, declared by the

manufacturer, that can be carried without damage under specified conditions, defined in terms of a current and time.

3.28.12 Rated Conditional Short-Circuit Current (I_{cc})

Value of prospective short-circuit current, declared by the manufacturer, that can be withstood for the total operating time (clearing time) of the short-circuit protective device (SCPD) under specified conditions.

NOTE— The short-circuit protective device may form an integral part of the panel or may be a separate unit.

3.28.13 Rated Reactive Power of the Panel (Q_n)

Total reactive power of the panel at the rated frequency and rated voltage, is calculated by the total impedance of the panel including reactors, if any.

NOTE— The reactive power is normally calculated at the fundamental frequency.

3.28.14 Rated Frequency (f_n)

The rated frequency of a panel is the value of frequency which designates it and to which the operating conditions are referred.

NOTE— The frequency should be within the limits specified in the relevant IS standards for the incorporated components. Unless otherwise stated by the manufacturer of the panel, the limits are assumed to be 98 % and 102 % of the rated frequency.

3.28.15 Clearance

The distance between two conductive parts along a string stretched the shortest way between these conductive parts

3.28.16 Creepage Distance

The shortest distance along the surface of the insulating material between two conductive parts

NOTE— A joint between two pieces of insulating material is considered part of the surface.

4 MARKING

The following minimum information shall be given by the manufacturer on a rating plate to be fixed on the panel or alternatively in an instruction sheet, on request of the purchaser.

- Manufacturer's name or trademark.
NOTE—The manufacturer is deemed to be the organization taking the responsibility for the completed panel.
- Identification number
- Type of switching, electro-mechanical or electronic or combination of both

- Reference to IS
- Month and year of manufacture
- Rated reactive power, Q_N in kilovars (kvar)
- Number of stages of panel and kvar of each stage
- Rated voltage, U_N in Volts (V)
- Rated frequency, f_N in Hertz (Hz)
- Minimum and maximum ambient temperatures in °C
- Short-circuit withstand strength, in amperes (kA)
- Installation – Indoor or outdoor
- Degree of protection
- Weight
- Dimensions

5 TESTS

5.1 Test Requirements

5.1.1 General

Tests specified are intended to verify compliance with the requirements laid down in this standard for a given type of APFC panel, as an assembly. The constituent components like capacitors, switching devices, reactors, instrument transformers, fuses, current limiting devices, control and auxiliary circuits, supporting insulators, accessories, etc. used in the panel shall comply with the requirements of relevant Indian Standards.

5.1.2 Test Conditions

Unless specified for a particular test or measurement, the ambient air temperature during the test shall be in the range of +10 °C to +40 °C.

The ac test voltage and measurements shall have a practically sinusoidal waveform and a frequency from 49 Hz to 51 Hz. Tolerances for test voltages shall be in accordance with IS 2071-1/ IEC 60060-1 (latest version).

5.1.3 Voltage Source Requirement

Power supply used for testing the panels shall be capable of continuous deliverance of power required for achieving the test voltage and test current across the terminals of the APFC panel under test. Suitable reactive compensation may be provided for achieving the same. Necessary safety measures shall be incorporated.

5.2 Classification of Tests

The tests are classified as

- Type tests (5.2.1)

- b) Routine tests (5.2.2)
- c) Acceptance tests (5.2.3)

5.2.1 Type Tests

Type tests are carried out in order to ascertain that, as regards design, material, construction and ratings, the panel complies with the specified characteristics and operational requirements detailed in this standard. If modifications are made to the components of the panel, type tests shall be repeated, but only in so far as such modifications are likely to adversely affect the result of these tests.

5.2.1.1 Criteria of approval

One or more identical panels shall be submitted for testing, along with relevant data. The testing authority shall issue a type test report / certificate, if the panels are found to comply with the requirements of type tests given in 5.2.1.

5.2.1.2 The following shall constitute type tests:

- a) Verification of Output (5.3)
- b) Dielectric tests (5.4)
 - i) Insulation resistance test (5.5)
 - ii) Power frequency withstand voltage test (5.6)
 - iii) Voltage withstand test between phases (5.7)
 - iv) Lightning Impulse voltage withstand test (5.8)
- c) Temperature rise test (5.9)
- d) Verification of the effectiveness of protective circuit (5.10)
- e) Short circuit withstand test (5.11)
- f) Verification of clearances (5.12)
- g) Verification of mechanical operation (5.13)
- h) Verification of the degree of protection of enclosure (5.14)
- i) Verification of the effectiveness of automatic PF correction (5.15)
- j) Measurement of transient over currents due to capacitor switching (5.16)

These tests may be carried out in any order. It is not essential to carry out the type test on a single panel. Same can be carried out on different panels of the identical design, type, rating and construction.

Unless otherwise specified, every panel to which it is intended to apply the type test shall have withstood satisfactorily the application of all routine tests given in 5.2.2.

The successful completion of each type test is also valid for panels of the same voltage rating, having

lower output ratings (kvar) with the same design, construction, type of switching device, type of current limiting device, IP class and other components, provided that they do not differ in any way that may influence the properties checked by the test.

5.2.2 Routine Tests

Routine tests are intended to detect faults, defects, deficiencies in materials and workmanship. They shall be carried out on every new APFC panel, before delivery. If purchaser so requests, he shall be supplied with a routine test report, detailing the results of tests.

5.2.2.1 The following shall constitute routine tests

- a) Dielectric test (5.4)
 - i) Insulation resistance test (5.5)
 - ii) Power frequency withstand voltage test (5.6)
- b) Verification of the effective connection between the exposed conductive parts of the panel and the protective circuit (5.10.1)
- c) Inspection of panel including inspection of wiring (5.17)
- d) Test for checking functional operation (5.18)

Routine tests may be carried out in any order.

5.2.3 Acceptance Tests

The routine and / or type tests, or some of them, may be repeated by the manufacturer in connection with any contract by agreement with the purchaser. The kind of tests, the number of samples that may be subjected to tests, and the acceptance criteria shall be as agreed between manufacturer and purchaser, and shall be stated in the contract.

5.3 Verification of Output (Type Test)

This test verifies the output rating (reactive power, kvar) of the panel and of the individual stages of the panel, against the declared values.

The panel shall be energised to the rated voltage at frequency between 49 Hz to 51 Hz using a suitable voltage source. Total output (kvar) of the panel and output of individual stages of the panel shall be measured with the help of a suitable power meter having accuracy of 1% or better.

Total output of the panel and output of individual stages of the panel are to be reported.

Alternatively, output current can be measured at rated voltage and frequency between 49 Hz to 51 Hz and calculated output (kvar) may be reported.

5.3.1 Output Tolerances

The output shall not differ from the rated output at rated frequency by more than

- 5% to +15 % for stages and panels of rating up to 100 kvar
- 5% to + 10 % for panel of rating above 100 kvar.

5.4 Dielectric Tests (Type and Routine test)

5.4.1 General

Each circuit/component of the panel shall be capable of withstanding

- Temporary over-voltages
- Transient over voltages

The ability to withstand temporary over-voltages and the integrity of solid insulation, is verified by the power frequency withstand voltage tests and the ability to withstand transient over-voltage is verified by the impulse voltage withstand test.

The rated insulation voltage of any circuit of the panel shall be equal to or higher than the rated voltage of the panel.

5.4.1.1 For routine test, the following dielectric tests shall be made

- Insulation resistance test (5.5)
- Power frequency withstand voltage test (5.6)

5.4.1.2 For type test, the following dielectric tests shall be made

- Insulation resistance test (5.5)
- Power frequency withstand voltage test (5.6)
- Voltage withstand test between phases (5.7)
- Lightning impulse voltage withstand test (5.8)

5.4.2 Application of Voltage

The panel shall be mounted as in normal use, in accordance with the manufacturer's instructions. In case of panels having non-metallic enclosure, the outer surface of the enclosure shall be covered by a metal foil and connected to the frame or the mounting plate.

The test voltage for Insulation resistance test (5.5), Power frequency withstand voltage test (5.6) and Lightning impulse voltage withstand test (5.8) shall be applied

- Between all terminals (shorted together) and the conductive structural parts of the panel (grounded) (refer to case 1 of Table 1).
- Between each terminal and all the other terminals connected to the conductive structural parts of the panel (grounded) (refer to case 2 of Table 1). Not applicable for electronically switched panels.

Test voltage shall be applied successively to all parts of the circuit as given in Table 1.

Test can be performed by energising all the stages at a time or by energising individual stages.

All electrical equipment of the panel shall be connected, except those items which, according to the relevant specifications, are designed for a lower test voltage; current-consuming apparatus (e.g. windings, measuring instruments, voltage surge suppression devices) in which the application of the test voltage would cause the flow of a current, shall be disconnected.

Anti-interference capacitors installed between live and exposed conductive parts shall not be disconnected and shall be capable of withstanding the test voltage.

For test voltage tolerances and the selection of test equipment, see IS 2071-1/ IEC 60060-1.

Table 1 Application of Test Voltage for Dielectric Tests
Case 1: Between terminals (shorted) and grounded enclosure

Test Arrangement (1)	Voltage Applied to (2)	Ground(G) / Earth(E) Connected to (3)
In case, control and auxiliary circuits (X, Y, Z,) are connected to the main circuit, they are to be disconnected from the main circuit (including neutral, n), while applying voltage. Protection devices like Switch Fuse unit/MCB/MCCB in the branch circuits shall be in close position. The Switching device (K) to be in open position. A ₁ shorted to A ₂ , B ₁ shorted B ₂ , C ₁ shorted to C ₂ shorted together	A, B, C and N shorted	X, Y, Z, n, F shorted
	X, Y, Z, n shorted	A, B, C, N and F shorted

Case 2: between each terminal and other terminals (shorted and) connected to grounded enclosure - Not applicable for electronically switched panels.

Test Arrangement (1)	Voltage Applied to (2)	Ground(G) / Earth(E) Connected to (3)
In case, control and auxiliary circuits (X, Y, Z,) are connected to the main circuit, they are to be disconnected from the main circuit (including neutral, n), while applying voltage. Protection devices like Switch Fuse unit/MCB/MCCB in the branch circuits shall be in close position. The Switching device (K) to be in open position.	A	B, C , N, X, Y, Z, n, F shorted
	B	A, C , N, X, Y, Z, n, F shorted
	C	B, A , N, X, Y, Z, n, F shorted

Notes

1 CT terminals / connections are to be grounded throughout the test for both electromechanically and electronically switched panels

2 Abbreviations used in the Table 1 are given below with reference to Fig. 1.

A, B, C: terminals of main circuit

N: Main Neutral

K: Switching device (electro-mechanical or electronic)

A1, B1, C1: terminals of main circuit up to incoming terminal of switching device

A2, B2, C2: terminals of main circuit from outgoing terminal of switching device

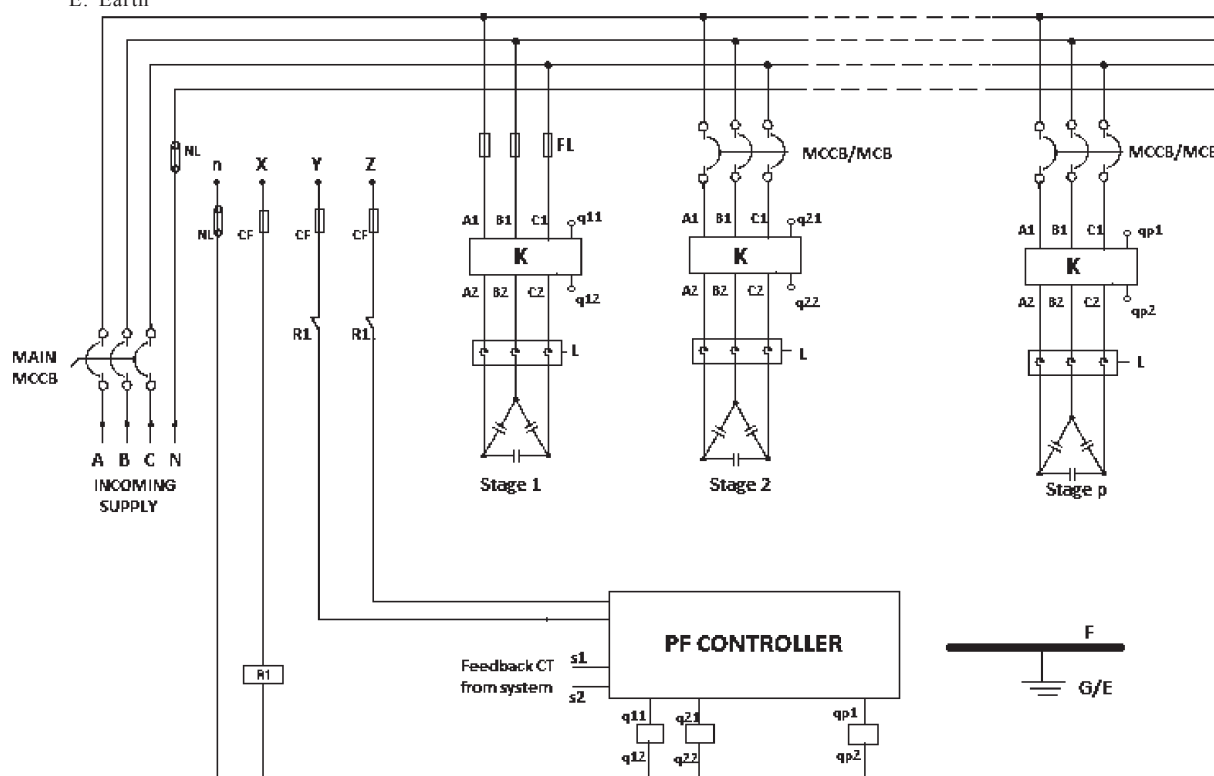
X, Y, Z: terminals of control circuit

n: neutral of control and auxiliary circuit

F: Metallic Enclosure / Frame

G: Ground

E: Earth



A, B, C	terminals of main circuit
N	Main Neutral
CF	Control fuse
NL	Neutral link
FL	Fuse link
MCCB	Moulded case circuit breaker
MCB	Miniature circuit breaker
L	Reactor
R1	Control Relay
q ₁₁ -q _{n1} q ₁₂ -q _{n2}	Terminals of the switching device connected to the control circuit

FIG. 1 SCHEMATIC OF POWER CIRCUIT AND CONTROL CIRCUIT OF APFC PANEL

5.5 Insulation Resistance Test (Routine Test)

5.5.1 Test Voltage

Measurement of insulation resistance (IR) shall be carried out using an insulation resistance measuring instrument by applying a voltage of at least 500 V dc for 1 minute. Application of voltage shall be as given in 5.4.2.

5.5.2 Passing Criteria

The test is deemed satisfactory if the measured value of insulation resistance is at least 50 M Ω .

5.6 Power Frequency Withstand Voltage Test (Routine and Type Test)

The power source shall have sufficient power to maintain the test voltage irrespective of any leakage currents. The ac test voltage shall have a practically sinusoidal waveform and a frequency between 49 Hz and 51 Hz.

5.6.1 Test Voltage

5.6.1.1 Testing of the main circuit

Clearance from live terminals to parts intended to be earthed shall be capable of withstanding the power frequency test voltage, either a.c. or d.c. given in Table 2. Application of voltage shall be as given in 5.4.2.

Duration of the test shall be 10 s for routine test and 60 s (with tolerance of +2/-0 s) for type test.

Table 2 Power Frequency Withstand Voltage for Main Circuits

Sl. No.	Rated Insulation Voltage U_i (line to line) V	Dielectric Test Voltage a.c. r.m.s. V	Dielectric Test Voltage d.c. r.m.s. V
(1)	(2)	(3)	(4)
i)	$U_i \leq 60$	1000	1415
ii)	$60 < U_i \leq 300$	1500	2120
iii)	$300 < U_i \leq 690$	1890	2670
iv)	$690 < U_i \leq 800$	2000	2830
v)	$800 < U_i \leq 1000$	2200	3110

5.6.1.2 Testing of auxiliary and control circuits

Auxiliary and control circuits, whether a.c. or d.c., that are not connected to the main circuit shall be subjected to the test voltage according to Table 3. Voltage shall be applied between shorted terminals and the conductive structural parts of the panel (grounded).

Duration of the test shall be 10 s for routine test and 60 s (with tolerance of +2/-0 s) for type test.

Table 3 Power Frequency Withstand Voltage for Auxiliary and Control Circuits

Sl. No.	Rated Insulation Voltage U_i (line to line) V	Dielectric Test Voltage a.c. r.m.s. V
(1)	(2)	(3)
i)	$U_i \leq 12$	250
ii)	$12 < U_i \leq 60$	500
iii)	$U_i > 60$	1500

5.6.2 Passing Criteria

During the test, neither puncture nor flashover shall occur.

5.7 Voltage Withstand Test between Phases (Type Test)

5.7.1 Test Voltage

The panel shall be energised to a voltage of 1.5 U_N a.c. for 10 s. During this test all the switching devices shall be in switched-on condition. Alternatively, test can be performed by energising individual stages.

For three phase panels, all the phases shall be energised with a three phase source.

During the test, the control and auxiliary circuits connected to the main circuit may be disconnected from the main circuit and powered from a separate source.

5.7.2 Passing Criteria

During the test, neither puncture nor flashover shall occur. Self-healing breakdowns, in case of self-healing type capacitors, are allowed.

5.8 Lightning Impulse Voltage Withstand Test (Type Test)

5.8.1 Test Voltage

Output of impulse voltage generator shall be adjusted to the required impulse voltage with the panel connected. The 1.2/50 μ s impulse voltage shall be applied. The tolerances for impulse voltage waveform shall be as follows:

- Test voltage (Peak): $\pm 3\%$
- Front time: $\pm 30\%$
- Time to half value: $\pm 20\%$

Five impulses of positive polarity followed by five impulses of negative polarity shall be applied at intervals of 1 s minimum.

After the change of polarity, it is permissible to apply some impulses of lower amplitude before the application of the test impulses.

Application of voltage shall be as given in 5.4.2.

Manufacturer shall declare the rated impulse withstand voltage for the panel.

5.8.1.1 Testing of the main circuit

Clearance from live terminals to parts intended to be earthed shall be capable of withstanding the test voltage given in Table 4 appropriate to the rated impulse withstand voltage.

The rated impulse withstand voltage for a given rated operational voltage shall not be less than that corresponding in Annex A to the nominal voltage of the supply system of the circuit at the point where the panel is to be used and the appropriate overvoltage category.

5.8.1.2 Testing of auxiliary circuits

Auxiliary circuits that are connected to the main circuit and operate at the rated operational voltage without any means for reduction of overvoltage shall be capable of withstanding the test voltage given in Table 4 appropriate to the rated impulse withstand voltage.

Auxiliary circuits that are not connected to the main circuit may have an overvoltage withstand capability different from that of the main circuit. The clearance of such circuits shall be capable of withstanding the appropriate impulse voltage in accordance with Annex A.

5.8.2 Passing Criteria

The test is considered to have been passed if there is no puncture or flashover, which can be ensured by the record of the impulse voltage waveform during the test.

5.9 Temperature Rise Test (Type Test)

The temperature-rise test is carried out to verify that the temperature-rise limits are not exceeding the specified values for different parts and components of the panel.

5.9.1 Test Method

The panel shall be mounted as in normal use, with all covers including bottom cover plates, etc., in place.

The temperature rise test shall be carried out on the panel with all capacitor units, reactors, if any, and other components connected. Test current shall be passed through the panel by energizing the panel with the help of a suitable voltage source. Suitable voltage may be applied to produce the specified test current. Control and auxiliary circuits shall be supplied with rated operational voltage.

At the discretion of the manufacturer, temperature rise test can be performed at higher ambient air temperatures by placing the panel in a heated enclosure. For such cases, the limits for temperature rise shall be as agreed upon between the manufacturer and the purchaser.

5.9.2 Test Current

The test current in terms of the rated current of the panel shall be one of the following:

- In the absence of any reactor or other current control devices, the test current shall not be less than 1.3 times the rated current of the panel.
- When protection or control systems are provided which limit the maximum current, then test current shall correspond to this maximum current. Otherwise panels shall be tested at 1.2 times the rated current.

The test current shall be maintained with a tolerance of 0 % to +2 %.

Guidelines for selection of the cross section of the external copper conductors used for connecting the panel to the test source are given in Annex B at Tables B.1 and Table B.2. For external aluminium conductors, size selection may be as given in Table B.3 and Table B.4.

5.9.3 Measurement of Temperature

During the test, temperature shall be measured with the help of suitable temperature sensors like thermocouples, at all points where temperature-rise limit must be observed. The thermocouples shall be protected from air currents and heat radiation.

Table 4 Dielectric Withstand Voltages for Lighting Impulse Test

S.No	Rated Impulse Withstand Voltage U_{imp} kV	Impulse Test Voltages and Corresponding Altitudes, $U_{1,2/50}$ kV				
(1)	(2)	(3)				
		Sea level	200 m	500 m	1000 m	2000 m
i)	2.5	2.95	2.8	2.8	2.7	2.5
ii)	4	4.8	4.8	4.7	4.4	4
iii)	6	7.3	7.2	7	6.7	6
iv)	8	9.8	9.6	9.3	9	8
v)	12	14.8	14.5	14	13.3	12

Temperature rise shall necessarily be measured on middle phase (Y-phase) of the following components.

- a) Incoming MCCB / ACB / Isolator
- b) Main busbar
- c) Fuse switch unit / Fuse link / MCB / MCCB on branch circuits
- d) Switching device (K)
- e) Reactor coil surface
- f) Reactor terminal

Temperature shall be measured at all points where a temperature rise limit must be observed. Particular attention shall be given to joints in conductors and terminals within the main circuit.

Temperature rise shall also be measured at the following components / locations

- a) Capacitor case
- b) Surface of the PF controller
- c) Outer surface of enclosure
- d) Panel enclosure air temperature

Ambient temperature shall be recorded during the test by means of at least three thermometers or thermocouples or other temperature-detecting devices equally distributed around the panel at about the average height of its current-carrying parts and at a distance of about 1 m from the panel and protected from direct heat radiation. Mean value of their readings shall be used for evaluation of the test. In order to avoid indication errors because of rapid temperature changes, the thermometers or thermocouples may be put into glass beakers containing about 0.5 liters of insulating oil.

During the last 2 hours of the test period, the change of ambient air temperature shall not exceed 1 K in 1 h. If this is not possible because of unfavorable temperature conditions of the test room, the temperature of an identical panel under the same conditions, but without current, can be taken as a substitute for the ambient air temperature. This

additional panel shall not be subjected to an undue amount of heat.

The test shall be made for a time sufficient for the temperature rise to reach a steady state value, but not exceeding 8 h. In practice, this condition is reached when the variation at all measured points (including the ambient air temperature) does not exceed 1 K/h. In any case the minimum duration of test shall be for 6 hours.

5.9.4 Passing Criteria

The temperature-rise of any part is the difference between the temperature of this part and the mean ambient air temperature outside the panel.

The temperature-rise limits given in Table 5 shall not be exceeding the specified value for various parts and components of the panel. The specified limits are applicable for the mean ambient air temperature up to +35 °C.

For tests conducted at other ambient air temperatures, the limits for temperature rise shall be as agreed upon between manufacturer and the purchaser.

During the test, neither puncture nor flashover shall occur in the panel.

The size and disposition of external conductors used for the test shall be stated in the test report.

5.10 Verification of the Effectiveness of Protective Circuit

5.10.1 Verification of the Effective Connection between the Exposed Conductive Parts of the Panel and the Protective Circuit (Routine and Type Test)

It shall be verified that the different exposed conductive parts of the panel are effectively connected to the protective circuit and their resistance between the incoming protective conductor and the relevant exposed conductive part does not exceed 0.1 Ω .

Table 5 Temperature-rise limits

Sl. No. (1)	Parts of Panel (2)	Temperature Rise K (3)
i)	Built-in components	
	a) Capacitor case (Refer to Table 1 of IS 13340/IEC 60831 and IS 13585/IEC 60931 for classification of temperature categories as A, B, C and D)	Temperature Category A: 15 Temperature Category B: 15 Temperature Category C: 15 Temperature Category D: 15
	b) Reactor coil surface	Class A: 50 Class E: 65 Class B: 70 Class F: 90 Class H: 115 The temperature shall necessarily be measured at the top region in between cores and coil of the middle phase.
	c) Case temperature of PF Controller	10

Table 5 (Continue)

Sl. No. (1)	Parts of Panel (2)	Temperature Rise K (3)
ii)	a) Terminals of external insulated conductors (<i>see</i> Note 2) b) Terminals of MCB/ MCCB/Isolator/ Contactor (<i>see</i> Note 2) c) Reactor terminals (<i>see</i> Note 2)	70 Bare copper : 60 Tinned copper: 65 Other metals: 65 The temperature rise limits for winding terminals of dry type reactors shall not exceed the limits given below: a) Bare terminals of copper, copper alloy, Aluminium or Aluminium alloy: 55 b) Silver-plated or nickel-plated terminals made of copper, copper alloy, Aluminium or Aluminium alloy: 80 c) Tin-plated terminals made of copper, copper alloy, Aluminium or Aluminium alloy: 70
iii)	Bus bar and conductors	Limited by a) mechanical strength of conducting material, b) possible effects on adjacent equipment, c) permissible temperature limit of the insulating materials in contact with the conductor, d) effect of the temperature of the conductor on the apparatus connected to it e) for plug-in contacts, nature and surface treatment of the contact material f) temperature rise limits have to be specified by the original manufacturer taking into account any additional measuring points and limits imposed by the components manufacturer. The limit is also decided based on the following factors: a) Ambient air temperature for LV capacitors are 40°C, 45°C, 50°C and 55°C for various categories namely A, B, C, and D (refer to IS 13340/ IEC 60831 and IS 13585/IEC 60931) b) The maximum admissible rise in capacitor case temperature is 15 K above the rated ambient air temperature. c) Heat dissipated from the bus bar shall not influence the performance of capacitors and other components of the panel Assuming all other criteria listed are met, a maximum temperature rise of 105 K for bare copper bus bars and conductors shall not be exceeded.
iv)	Manual operating means: a) of metal b) of insulating material	(1) 15 (2) 25 Manual operating means within panels which are only accessible after the panel has been opened, for example draw-out handles which are operated infrequently, are allowed to assume a 25 K increase on these temperature-rise limits.
v)	Accessible external enclosures and covers: a) metal surfaces b) insulating surfaces	(1) 30 (2) 40 Unless otherwise specified, in the case of covers and enclosures, which are accessible but need not be touched during normal operation, a 10 K increase on these temperature-rise limits is permissible. External surfaces and parts over 2m from the base of the panel are considered inaccessible.
vi)	Discrete arrangements for plug and socket-type connections	This allows a degree of flexibility in respect of equipment (e.g. electronic devices) which is subject to temperature-rise limits different from those normally associated with switchgear and control-gear. Determined by the limit for those components of the related equipment of which they form a part.
vii)	Air temperature inside the panel	The temperature-rise limit to be specified by the manufacturer of the panel, taking into consideration the safety limits.

Table 5 (Conclude)

NOTES

1 The specified limits are applicable for the mean ambient air temperature up to +35°C

2 For deciding the temperature rise limits for terminals where two limits may be applicable, the lower limit among the two shall be considered. For example, the external insulated conductor connected to MCCB, the temperature rise limit for MCCB terminal shall be considered as the limit.

Verification shall be made employing a resistance measuring instrument or arrangement which is capable of driving a current of at least 10 A a.c. or d.c. into an impedance of 0.1Ω between the points of the resistance measurement.

NOTE — It may be necessary to limit the duration of the test to 5 s where low-current equipment otherwise may be adversely affected by the test.

5.10.2 Verification of the Short-Circuit Strength of the Protective Circuit by Test (Type Test)

This test does not apply for panels according to 5.11.2.

The capacitor banks and reactors, if any, shall be bypassed or disconnected from the panel for conducting this test. Electronically switched devices of the panel shall also be excluded from test.

A single-phase test supply shall be connected to the incoming terminal of one phase and to the terminal for the incoming protective conductor. When the panel is provided with a separate protective conductor, the nearest phase conductor shall be used. For each representative outgoing unit, a separate test shall be made with a bolted short-circuit connection between the corresponding outgoing phase terminal of the unit and the terminal for the relevant outgoing protective conductor.

Each outgoing unit on test shall be fitted with its intended protective device. Where alternative protective devices can be incorporated in the outgoing unit, the protective device which lets through the maximum values of peak current and I^2t shall be used.

For this test, the frame of the panel shall be insulated from earth. The test voltage shall be equal to 1.05 times the single-phase value of the rated operational voltage (U_e). Unless otherwise agreed between the original manufacturer and the user, the value of the test current in the protective conductor shall be at least 60 % of the phase current during the three-phase test of the panel.

All other conditions of this test shall be analogous to 8.2.3.2 of IS 8623 -1/IEC 60439-1.

5.10.3 Passing Criteria

The continuity and the short-circuit withstand strength of the protective circuit, whether it consists

of a separate conductor or the frame, shall not be significantly impaired. Besides visual inspection, this may be verified by measurements with a current in the order of the rated current of the relevant outgoing unit. Deformation of the enclosure or of the internal partitions, barriers and obstacles due to short-circuit is permissible to the extent that the degree of protection is not apparently impaired and the clearances or creepage distances are not reduced to values, which are less than those specified in 5.12.

NOTES

1 Where the frame is used as a protective conductor, sparks and localized heating at joints are permitted, provided they do not impair the electrical continuity and provided that adjacent flammable parts are not ignited.

2 A comparison of the resistances measured before and after the test, between the terminal for the incoming protective conductor and the terminal for the relevant outgoing protective conductor, gives an indication of conformity with this condition.

5.11 Short-Circuit Withstand Test (Type Test)

5.11.1 General

Short-circuit withstand strength declared by the original manufacturer shall be verified.

5.11.2 Circuits of Panels Which Are Exempted From the Verification of the Short-Circuit Withstand Strength

A verification of short-circuit withstand strength is not required for the following:

- Panels having a rated short-time withstand current or rated conditional short-circuit current not exceeding 10 kA r.m.s.
- Panels protected by current-limiting devices having a cut-off current not exceeding 17 kA at the maximum allowable prospective short-circuit current at the terminals of the incoming circuit of the panel.
- Auxiliary circuits of panels intended to be connected to transformers whose rated power does not exceed 10 kVA for a rated secondary voltage of not less than 110 V, or 1.6 kVA for a rated secondary voltage less than 110 V, and whose short-circuit impedance is not less than 4 %.

All other circuits shall be verified.

5.11.3 Test Procedure and Criteria of Acceptance

The short circuit withstand test shall cover the incomer MCCB / ACB / Isolator and complete busbar system.

The capacitor banks and reactors, if any, shall be bypassed or disconnected from the panel for conducting this test. Electronically switched devices of the panel shall also be excluded from test.

Test procedure and accepting criteria shall be done as per IS 8623-1/IEC 60439 – 1.

5.12 Verification of Clearances (Type Test)

Clearances between phases and phase to body/ground/neutral are intended to provide insulation co-ordination within the panel. For dimensioning clearances between separate circuits, the highest voltage ratings shall be used (rated impulse withstand voltage for clearances).

The clearances shall be sufficient to enable the declared rated impulse withstand voltage (U_{imp}) of a circuit to be achieved. The clearances shall be as specified in Table 6.

5.13 Verification of Mechanical Operation (Type Test)**5.13.1 General**

Test is not applicable for devices like MCB, MCCB, ACB, with-drawable circuit breaker, etc., which have already been type tested according to their relevant product standard unless their mechanical operation has been modified by their mounting.

Table 6 Minimum Clearances in Air

S1 No.	Rated Impulse Withstand Voltage, U_{imp} kV	Minimum Clearances mm
(1)	(2)	(3)
i)	2.5	1.5
ii)	4	3.0
iii)	6	5.5
iv)	8	8.0
v)	12	14.0

NOTE — The values of minimum clearances in air are based on 1.2/50 μ s impulse voltages, for barometric pressure of 80 kPa equivalent to normal atmospheric pressure at 2000 m above sea level.

All enclosures or partitions including locking means and hinges for doors shall have mechanical strength sufficient to withstand the stresses to which they may be subjected in normal service, and during short-circuit conditions.

The mechanical operation of removable parts, including any interlocking devices, shall be verified after installation in the panel.

5.13.2 Test Method

Mechanical operation cycle consists of - open interlocking devices - open enclosure or partition - close enclosure or partition - close interlocking devices. This constitutes one cycle.

The number of operating cycles shall be

- 200 for enclosures or partitions including interlocking devices in the main circuit
- 25 for enclosures or partitions including interlocking devices in the branch circuit.

5.13.3 Passing Criteria

The test is considered to have been passed if the operating conditions of the panel, interlocking devices, specified degree of protection etc., have not been impaired and if the effort required for operation is practically the same as before the test.

5.14 Verification of the Degree of Protection of Enclosure (Type Test)

The degree of protection provided in the panel shall be verified in accordance with IS / IEC 60529.

IP tests shall be carried out:

- with all covers and doors in place and closed as in normal service;
- in a de-energised state unless stated otherwise by the original manufacturer.

Panels having a degree of protection of IP 5X shall be tested according to category 2 in 13.4 of IS/IEC 60529: 2001.

Panels having a degree of protection of IP 6X shall be tested according to category 1 in 13.4 of IS/IEC 60529: 2001.

The test device for IP X3 and IP X4 as well as the type of support for the enclosure during the IP X4 test shall be stated in the test report.

The IP X1 test may be carried out by moving the drip box instead of rotating the panel.

Ingress of water in the IP X1 to IP X6 tests on a panel is permissible only if its route of entry is obvious and the water is only in contact with the enclosure at a location where it will not impair safety.

The IP 5X test is deemed to be a failure if harmful amount of dust is visible on electrical equipment housed within the enclosure.

5.15 Verification of the Effectiveness of Automatic PF Correction (Type Test)**5.15.1 General**

APFC panels shall be capable of sensing the

prevailing PF of the load and automatically correct it to the target value. This test is intended to verify the function of APFC panels for automatic PF correction. Effectiveness of automatic PF correction can be verified either in terms of PF value achieved or kvar compensation or reduction in mains current, by way of switching suitable stage (s) of APFC panel. The procedure of kvar compensation for PF correction shall be as follows.

The test is carried out by connecting a variable inductive load, which could be either a shunt reactor bank or an electronic load or a combination of both. Rating of the inductive load shall be capable of delivering necessary reactive power for switching all stages of the APFC panel from the minimum stage to the maximum stage, individually and / or sequentially.

APFC panels of rating, for example up to 100 kvar, may be tested by switching all its stages in one step. For testing panels of rating beyond 100 kvar, laboratory test setup may have practical limitations in switching all the stages of APFC panels in one step. Therefore, automatic PF correction capability of the panel can be verified either for the panel as a whole or for individual stages or for combination of multiple stages depending on the test set up rating.

NOTES

1) Feedback CT of appropriate rating and accuracy shall be used for sensing the prevailing PF by the APFC panel. Accuracy of the CT shall be 0.5 class or better (refer to IS 2705).

2) A suitable resistive load (say, 1 Kw) may be connected for the purpose of proper sensing of power factor.

3) Minimum stage that can be switched on depends upon the minimum current sensed by the feedback CT which will be, generally, equivalent to 5 % of the rated current of CT.

5.15.2 Test Procedure

Test shall be carried out at rated voltage of the panel. Sequence of test shall be as follows:

- a) The panel shall be mounted as in normal use and PF controller shall be set to function in automatic PF correction mode as per manufacturer's instruction.

- b) APFC panel and variable inductive load shall be connected in parallel to a common bus which will be connected to the power supply. A feedback CT shall be installed on the power supply line for sensing the load PF by the PF controller.
- c) The target PF, as declared by the manufacturer, shall be set in the PF controller of the APFC panel. If no target PF is declared by the manufacturer, then, target PF could be set as 0.98 lag.
- d) Verification of correction to lagging PF: Suitable inductive load is turned ON into the circuit so as to switch ON single or multiple stages of the panel. Switching may happen in accordance with the switching programme defined in the PF controller. If programme is not defined in the controller, switching may be in the ascending order of stage size of the panel. Inductive load (kvar) turned ON shall be either equal to or greater than the stage size (s) of the panel to be switched, however, shall not exceed the size of the next higher stage. Test shall be conducted so that all stages of the panel are switched in sequence, individually or in combination. Examples of switching are given in Annex C.
- e) Verification of correction to leading PF: This test can be carried out in continuation to verification of correction to lagging PF. Inductive load in the circuit is turned OFF so as to switch OFF single or multiple stages of the panel. Test shall be conducted till all the stages of the panel are switched OFF.
- f) Inductive load turned ON and panel stages automatically switched ON are noted down for lagging PF correction. Similarly, inductive load turned OFF and panel stages automatically switched OFF are noted down for leading PF correction.

The observations may be reported as follows

(i) Lagging PF correction

Panel Stage(s) to be switched ON (Q_s)	Inductive Load turned ON (Q_L) ^{a)}	APFC panel stage(s) automatically switched ON (Q_c)	Total size of capacitor stages switched ON ($Q_L - Q_c$)	Passing criterion
				$(Q_L - Q_c)$ shall be equal to $(Q_L - Q_s)$

^{a)} Q_L shall be either equal to or greater than the stage size (s) to be switched, however, shall not exceed the size of the next higher stage.

(ii) Leading PF correction

Panel Stage(s) to be switched OFF (Q_s)	Inductive Load turned OFF (Q_L) ^{a)}	APFC panel stage(s) automatically switched OFF (Q_c)	Total size of capacitor stages switched OFF ($Q_L - Q_c$)	Passing criterion
				$(Q_L - Q_c)$ shall be equal to $(Q_L - Q_s)$
^{b)} Q_L shall be either equal to or greater than the stage size (s) to be switched OFF				

5.15.3 Passing Criteria

- APFC panel stage (s) shall switch ON or OFF so as to compensate the inductive load turned ON or OFF.
- Switching sequence of panel stages shall follow the programme defined in the PF controller. If programme is not defined in the controller, switching shall happen in the ascending order of stage size of the panel in accordance with inductive load connected or removed from the circuit.

Alternatively, suitable procedure in terms of PF correction achieved against the target PF, may also be followed.

5.16 Measurement of Transient over Currents Due To Capacitor Switching (Type Test)**5.16.1 General**

Transient over currents are expected when a section of a capacitor bank is switched alone or in parallel with other steps that are already energized (*see* Annex D).

The effect of transients is more severe in mechanically switched panels as compared to electronically switched panels. In case of mechanically switched panels, current limiting devices like pre-insertion resistor, series reactors, etc., are generally used to limit the amplitude of peak current and duration of transient.

This test is for measuring the peak magnitude of transient over current due to capacitor switching and for verifying the efficacy of current limiting devices used in APFC panels.

Amplitude and frequency of transient overcurrent are influenced by factors such as the short circuit impedance of the power supply, the amount of energized capacitance switched in parallel and the

instant of the switching. Switching transients during single switching (*see* Annex D) are influenced by short circuit impedance of the supply. Switching transients during parallel switching are independent of short circuit impedance of the power supply and are dependent on circuit components of APFC panel. In order to exclude the influence of short circuit impedance of the power supply, which may vary from laboratory to laboratory, measurement of transient over currents is considered only for parallel switching.

The maximum inrush current occurs during switching of the highest size stage in parallel with remaining stages in energized condition.

5.16.2 Test Method

Test shall be carried out at rated voltage of the panel. Sequence of test shall be as follows:

- The panel shall be mounted as in normal use.
- The panel and suitable variable inductive load shall be connected in parallel to a common bus which will be connected to the power supply.
- Inrush current is measured for each stage of the panel. If the APFC panel has two or more identical stages, then test is carried out on one of the identical stages.
- The inductive load is adjusted so that the test stage is switched in parallel with remaining stages in energized condition. Peak of transient over current is measured along with the point of switching, simultaneously on all three phases. Switching operations are continued till peak switching has occurred or for a minimum of 5 switching operations. Maximum of the measured peak current is reported for each

test stage. Time interval between two switching operations shall be as declared by the manufacturer or 5 minutes, minimum.

Suitable oscilloscope (of bandwidth 100 kHz, minimum), voltage probes and current probes with appropriate response characteristics like frequency band and current amplitude based on the rating of the panel shall be employed for measuring the transient over currents.

The observations to be reported as follows

Trial Number	Panel stage to be switched (kvar)	Panel stages already energised (kvar).	Peak of transient over current (maximum)
1			
2			
3			
4			
5			

5.16.3 Passing Criteria

Peak value of the transient over current due to parallel switching of capacitor banks shall not exceed the value declared by the manufacturer. However, it shall not exceed $100 I_N$ (r.m.s. value).

In case of electronically switched panels, the transient over current shall not exceed $10 I_N$ (r.m.s. value) or as declared by the manufacturer.

5.17 Inspection of the Panel Including Inspection of Wiring (Routine Test)

The following physical inspection shall be carried out:

- Conformity of the panel to the circuit and wiring diagrams, technical data, etc., provided by the manufacturer
- Verification of the information and markings specified in Markings 4 and conformity of the panel to these information
- Visual inspection of the prescribed degree of protection
- Connections, especially screwed and bolted connections

In some cases, it may be necessary to repeat this test at site, prior to installation of the panel. In this case, a special agreement shall be made between manufacturer and user.

5.18 Test for Checking Functional Operation (Routine Test)

The panel shall be energised to rated voltage through

a suitable voltage source. Each stage of the panel is switched on and current drawn is measured. Individual stage current and total panel current shall be within $\pm 5\%$ of the rated current.

Output (kvar) of individual stages of the panel is calculated as per 5.3. Output tolerance shall be in accordance with 5.3.1.

Function of meters, switches and indicators shall be checked for their functionality.

The panel shall be provided with meters for display of voltage (V), current (A), frequency (Hz) and power factor. Accuracy of metering provided in the panel shall be within 1%.

6 GUIDE FOR DESIGN, INSTALLATION, OPERATION AND SAFETY

6.1 General

For proper design and installation, it is essential to perform a detailed system study mainly to assess (a) the present load, loading pattern, existing PF and required reactive compensation, (b) power quality and harmonics, (c) expected growth in load for next 5 years and (d) any special system requirement. Outcome of such system study shall be made considered for designing APFC panels for the required application.

Unlike most electrical apparatus, shunt capacitors, whenever energized, operate continuously at full load or at loads that deviate from this value only as a result of voltage and frequency variations

Overstressing and overheating shorten the life of a capacitor, and therefore the operating conditions (that is temperature, voltage and current) should be strictly controlled.

It should be noted that the introduction of a capacitance in a system might produce unsatisfactory operating conditions (for example amplification of harmonics, self-excitation of machines, overvoltage due to switching, unsatisfactory working of audio-frequency remote-control apparatus, etc.).

Because of the different types of capacitors and the many factors involved, it is not possible to cover, by simple rules, installation and operation in all possible cases. The following information is given with regard to the more important points to be considered. In addition, the instructions of the manufacturer and the power supply authorities shall be followed.

6.2 Choice of Components

The choice of components of an APFC panel shall be carried out with careful reference to compliance between their ambient air temperature and that of the panel itself.

6.3 Design

6.3.1 General

APFC panel shall have provision to read system voltage and current. For power factor correction, APFC panels get the feedback from the current transformer (CT) installed in the system. Therefore, CT of suitable ratio and accuracy is to be provided in the panel for measuring the current drawn by the panel. Provision shall be made in the panel for monitoring panel current.

6.3.2 Power Factor Correction System Enclosed Within a Main Switchboard

The equipment needed for the automatic correction of power factor in an installation, including controller, fuses, switching devices, capacitors and reactors (chokes), can be installed as an integral part of the main switchboard.

This equipment can be also installed in a separate shell of the main board or simply as an added part in the common main switchboard shell.

6.3.3 Free Standing Power Factor Correction System

The equipment is free standing and usually installed adjacent or close to the main switchboard or relevant sub-board. It generally has a main bus bar arrangement of the required fault level to match the adjacent main switchboard or sub-board. or the required fault current of that section of the installation.

This bus bar section is bus barred or cabled back to the main supply of the installation.

Feeding off this bus bar section is a group of fuses, circuit-breaker or fused switch which are wired to a switching device and then to the capacitor banks.

6.3.4 Automatic Power Factor Correction System with Remote Mounted Capacitors

All components except for the capacitors are mounted in the control cubicle. The capacitors and the required reactors, if any, are mounted on a remote mounting rack. This arrangement is generally used if there is a problem with space requirements or to allow further dissipation of heat. It is important to note that power factor component equipment such as fuses, capacitors; reactors, etc. generate a significant amount of heat.

6.3.5 Communication Ports / Data Interfaces

If the purchaser desires, an Ethernet gateway or main meter with Ethernet capabilities shall be provided. This feature can be used for monitoring and recording of data (like voltage (V), current (A), kvar, frequency (Hz) and power factor) and / or for transferring data to electrical SCADA.

6.3.6 Tamper proof Design

If purchaser desires, suitable tamperproof design shall be provided.

6.3.7 Compartmentalization

The general arrangement of a power factor correction panel can be made in sections, which can be arranged in separate compartments or in a single configuration.

- a) Bus bar, main connection and/or main isolation;
- b) Capacitor bank fuses or circuit-breakers and/or contactors;
- c) Reactors for harmonic control purposes;
- d) Capacitors;
- e) Control fuses, terminals and controller

6.3.8 Choice of Rated Voltage

The rated voltage of the capacitor shall be at least equal to the service voltage of the network to which the capacitor is to be connected, account being taken of the influence of the presence of the capacitor itself.

In certain networks, a considerable difference may exist between the service voltage and rated voltage of the network, details of which should be furnished by the purchaser, so that due allowance can be made by the manufacturer. This is important for capacitor banks, since their performance and life may be adversely affected by an undue increase of the voltage across the capacitor dielectric.

If no information, to the contrary, is available, the service voltage shall be assumed as equal to the rated (or declared) voltage of the network.

Where circuit elements are inserted in series with the capacitor to reduce the effects of harmonics, etc., the resultant increase in voltage at the capacitor terminals over and above the service voltage of the network necessitates a corresponding increase in the rated voltage of the capacitor.

When determining the voltage to be expected on the capacitor terminals, the following considerations shall be taken into account:

- a) Shunt-connected capacitors may cause a voltage rise from the source to the point

where they are located (*see* Annex D); this voltage rise may be greater due to the presence of harmonics. Capacitors are therefore liable to operate at a higher voltage than that measured before connecting the capacitors.

- b) The voltage on the capacitor terminals may be particularly high at times of light load conditions (*see* Annex D); in such cases, some or all of the capacitors should be switched out of circuit in order to prevent overstressing of the capacitors and undue voltage increase in the network.

Only in case of emergency should capacitors be operated at maximum permissible voltage and maximum ambient temperature simultaneously, it shall be only for short periods of time.

NOTES

- 1) an excessive safety margin in the choice of the rated voltage U_N should be avoided, because this would result in a decrease of output.
- 2) Refer to IS 13340/IEC 60831 and IS 13585/IEC 60931 concerning maximum permissible voltage.

6.3.9 Special Service Conditions

Apart from the conditions prevailing at both limits of the temperature category, the most important conditions about which the manufacturer shall be informed are the following:

- a) Rapid mould growth

Mould growth does not develop on metals, ceramic materials and certain kinds of paints or lacquers. For other materials, mould growth may develop in humid places, especially where dust, dirt, etc. can settle.

The use of fungicidal products may improve the behaviour of these materials, but such products do not retain their poisoning property for more than a certain period.

- b) Corrosive atmosphere

Corrosive atmosphere is found in industrial and coastal areas. It should be noted that in climates of higher temperature the effects of such atmosphere might be more severe than in temperate climates. Highly corrosive atmosphere may be present even in indoor installations.

- c) Pollution

When panels are mounted in a location with a high degree of pollution, special precautions shall be taken.

- d) Altitude exceeding 2000 m

Capacitors used at altitudes exceeding 2000 m are subject to special conditions. Choice of type of

capacitor should be made by agreement between purchaser and manufacturer.

6.3.10 Switching and Overload Protection

Capacitor overload capacities are given in IS 13340 / IEC 60831 and IS 13585/IEC 60931. These limits are however larger than the ones applicable for the banks. The switching and protective devices and the connections shall be designed to carry continuously a current of at least 1.3 times the current that would be obtained with a sinusoidal voltage of an r.m.s. value equal to the rated voltage at the rated frequency.

The switching and protective devices and the connections shall also be capable of withstanding the electro dynamic and thermal stresses caused by the transient over currents of high amplitude and frequency that may occur when switching on.

Such transients are to be expected when a bank or a step is switched in parallel with others that are already energized. It is common practice to increase the inductance of the connections in order to reduce switching current, although this increases the total losses. Care should be taken not to exceed the maximum permissible switching current of capacitors and switching devices.

When considering electro dynamic and thermal stresses, which results in the risk of leading to excessive dimensions, special precautions, such as those mentioned in IS 13340/IEC 60831 and IS 13585/IEC 60931 for the purpose of protection against over currents, should be taken.

NOTE

- 1) in certain cases, for example when the banks are automatically controlled, repeated switching operations may occur at relatively short intervals of time. Switchgear and fuses should be selected to withstand these conditions.
- 2) Switching devices connected to a bus bar which is also connected to a bank, may be subjected to special stress in the event of switching on a short-circuit.
- 3) Devices for switching parallel steps and their associated protective equipment should be able to withstand the inrush current (amplitude and frequency) resulting when one bank connected to a bus bar to which other bank(s) are already connected.

It is recommended that capacitors be protected against over current by means of suitable over current relays, which are adjustable to operate the switching devices when the current exceeds the permissible limit specified in IS 13340/IEC 60831 and IS 13585/IEC 60931. Fuses do not generally provide suitable over current protection.

NOTE 4 — Depending on the design of capacitors; their capacitance will vary more or less with the temperature.

If iron-core reactors are used, attention should be paid to possible saturation and overheating of the core by harmonics.

Any bad contacts in capacitor circuits may give rise to arcing; causing high-frequency oscillations that may overheat and overstress the capacitors. Regular inspection of all capacitor equipment contacts is therefore recommended.

6.3.11 Ingress Protection Designation (IP)

Most APFC panels are installed in main switch rooms or adjacent to main boards: in these conditions IP 20 may be sufficient. Other IP levels should be agreed between manufacturer and purchaser.

Degrees of protection (IP) rating for panels to be installed outdoor may be increased up to IP 54. Careful consideration is to be paid to the design of the ventilation of the cubicle.

6.3.12 Accessibility of Components

The cubicle and equipment shall be arranged so that in the event of a component failure, components can be easily replaced.

The arrangement of cabling to the capacitor(s) should allow easy regular maintenance checks.

6.4 Response Time of the Panel for PF Correction

Response time of the panel is the interval of time between the instant of sensing the prevailing PF and the instant of correcting it to the target PF. Response time of APFC panel can be measured as the interval of time between the instant of sensing the lagging or leading current and the instant of final PF correction by way of switching necessary stages of the panel.

Procedure for measurement of response time of the panel for PF correction is given in Annex E for information.

6.5 Installation and Operation

6.5.1 General

During installation, care shall be taken with regard to polarity of CTs and phase sequence of main circuit.

6.5.2 Electrical Environment

6.5.2.1 Harmonics

The connection of PFC (power factor correction) equipment onto a system containing harmonics may reduce the life of the PFC equipment. The damaging effects of harmonics can be mitigated by the use of a suitable detuning reactor in series with each capacitor step.

6.5.2.2 Voltage spikes

Voltage spikes should be avoided. If switching components are selected which are specifically recommended for capacitor applications, the problem should not arise. Nevertheless, equipment does deteriorate with time and worn contacts should be replaced during regular maintenance checks.

6.5.2.3 Load assessment

The decision of where to apply the power factor correction is determined by a number of factors, including cost and available space:

- a) Determine where the loads with the low power factor are situated: the PFC can be located at these points;
- b) Generally, it is more practical to locate PFC at the main switchboard, where space is available. In this case, the PFC will correct the power factor of the whole load and maintenance of the PFC is in one location

6.5.3 Secondary Effects of the PFC System

6.5.3.1 Harmonic distortion

PFC equipment when connected onto a system where harmonics are being generated will generally increase the amplitude of the harmonics, unless a well suited detuning reactor is placed in series with each capacitor step.

The increase in harmonics will not only affect the life of the capacitors but could cause problems with other electric and electronic equipment in the system.

6.5.3.2 Rise of ambient temperature

PFC equipment produces heat from the losses developed in capacitors, reactors, resistors, coils, etc. This heat adds to the ambient temperature in the surrounding area. It is important to ensure that adequate ventilation is provided in the operating room in order to maintain good air circulation around the PFC unit.

6.5.4 Over Voltages

IS 13340/IEC 60831 and IS 13585/IEC 60931 specify overvoltage factors. With the manufacturer's agreement, the overvoltage factor may be increased if the estimated number of over voltages is lower, or if the temperature conditions are less severe. These power-frequency overvoltage limits are valid, provided that transient over voltages are not superimposed on them. The peak voltage shall not exceed "2 times the given r.m.s. value.

Capacitor banks that are liable to be subjected to high over voltages due to lightning should be adequately protected.

6.5.5 Overload Currents

Before ordering PFC equipment, consideration should be given to checking the conditions in the system at the place of installation (for instance, presence of harmonic distortion, or use of ripple control frequencies).

Capacitors should never be operated with currents exceeding the maximum value specified in IS 13340/IEC 60831 or IS 13585/IEC 60931.

Overload currents may be caused either by excessive voltage at the fundamental frequency, or by harmonics, or both. The chief sources of harmonics are rectifiers, power electronics devices and saturated transformer cores.

If the voltage rise at times of light load is increased by capacitors, the saturation of transformer cores may be considerable. In this case, harmonics of abnormal magnitude are produced, one of which may be amplified by resonance between the transformer and capacitor. This is a further reason for recommending the disconnection of capacitor banks at times of light load.

If the capacitor current exceeds the maximum value specified in IS 13340/IEC 60831 or IS 13585/IEC 60931, while the voltage is within the permissible limit of $1.10 U_n$ specified in IS 13340 / IEC 60831 or IS 13585/IEC 60931, the predominant harmonic should be determined in order to find the best remedy.

The following remedies should be considered:

- a) Move some or all of the capacitor units to other parts of the system fed by another transformer;
- b) Connect a reactor in series with the capacitor unit, to lower the resonant frequency of the circuit to a value below that of the disturbing harmonic.

The voltage waveform and the network characteristics should be determined before and after installing the capacitor bank. When sources of harmonics such as large power electronic devices are present, special care should be taken.

Transient over currents of high amplitude and frequency may occur when capacitors are switched on. Such transient effects are to be expected when a section of a capacitor bank is switched in parallel with other steps that are already energized (see Annex D).

It may be necessary to reduce these transient over currents to acceptable values in relation to the capacitor unit and to the equipment by switching on the capacitors through a resistor (resistance switching), or by the insertion of reactors into the supply circuit of each section of the bank.

The peak value of the over currents due to switching operations shall be limited to a maximum of $100 I_N$ (r.m.s. value) or to the maximum capability of the contactors, whichever is the smaller.

6.6 Safety

6.6.1 Discharging Devices

Each capacitor bank or step should be provided with means for discharging the bank after disconnection from the network.

The specified discharging times may be met by applying either internal (incorporated) discharge resistors on each capacitor or external discharge devices rated for the entire capacitor equipment.

Since the residual voltage at energization must not exceed 10 percent of the rated voltage, discharge resistors with lower resistance or additional switched discharge device may be needed, for the automatically controlled capacitors.

Before touching any live parts, allow at least 5 min for the bank to self-discharge and then short-circuit each capacitor terminal together and ground.

6.6.1.1 Internal resistors

Internal resistors are generally built into the individual capacitors. They are designed to ensure the discharge of each capacitor and therefore the whole bank. In a bank with several sections of capacitors in series, the residual voltage on the bank terminal is equal to the sum of the residual voltage in each section.

6.6.1.2 External discharge devices

External discharge devices may be used. Each device should be adapted to the conditions existing at the site of erection of the equipment and have suitable strike distance, creep age path and insulation level. If the capacitors have no internal discharge resistors, there should be no isolating device between the capacitor bank and the discharge device.

Discharge reactors may be used connected directly in parallel with the capacitor steps. Usually, two reactors are connected line-to-line across two phases because of economical reasons. Under operating conditions, only the magnetizing current flows in the reactor. When the capacitor equipment is switched off, all the energy stored circulates through the coil in a few seconds. Most of the energy is dissipated in the reactor. The number of discharges per unit of time should be restricted so that no overheating of the discharge reactor occurs.

Windings of transformers or motors may be considered as suitable impedances as well as the primary of voltage transformers.

6.6.2 Discharging after Disconnection

A disconnected capacitor installation should completely self-discharge no matter where the discharge device is located, be it directly at each capacitor or at the connecting terminals of the equipment.

However, a capacitor installation comprising series connections and star connections, which have undergone puncturing or internal or external arcing, may not be discharged completely through discharge devices connected to the terminals of the capacitor installation. Although there is no voltage measurable at the equipment terminals, dangerous amounts of stored energy may exist in the bank. These so-called “trapped charges” may persist over a period of several months and can only be discharged by individual discharging of each section of the bank. These inter-connections, therefore, shall be short-circuited to earth before handling.

It is important to note that a discharging device is not suitable for short-circuiting the capacitor terminals together and to ground before and during handling.

NOTES

1) Capacitors connected directly to other electrical equipment providing a discharge path shall be considered properly discharged, provided that the circuit characteristics are such as to ensure the discharge of the capacitor within the times specified in IS 13340/IEC 60831 and IS 13585/IEC 60931.

2) Discharge circuits must have adequate current carrying capacity to discharge the capacitor from the peak of the $1.3 U_N$ over-voltage.

6.6.3 Earth Connection

If the metal container of the panel and capacitor units is at earth potential in normal service, it shall be possible to connect it to earth in a reliable way, and clearly marked with the symbol.

To enable the potential of the metal container of the panel and capacitor units to be fixed, and to enable carry the fault current in the event of a breakdown to the container, the container shall be provided with a connection capable of carrying the fault current.

6.6.4 Other Safety Requirements

Panel shall comply with the relevant general safety regulations for power installations, that is, Indian Electricity Rules.

6.6.5 Fire Hazard In Case Of Failure

Capacitors contain flammable materials, i.e. dielectric film and/or paper, oil, etc. The bank should be arranged with consideration of a possible fire hazard in case of a failure of a component. The two areas to be considered are as follows:

- a) Adjacent areas to the capacitors. Normally capacitors are manufactured in metal cans or are installed in a segregated metal section or separated from other components by metal barriers. Power and control cables in these areas should be kept to a minimum and carefully cabled, so as to avoid direct contact to capacitor cases.
- b) Adjacent areas around the reactors. Where reactors (chokes and filters) are installed, power and control cables should be kept to a minimum around these components or at least supported away from the laminated steel cores of these components.

6.6.6 Human and Property Damage

The manufacture of the panel should have components arranged in a manner so that when carrying out maintenance, personnel are not subject to accidental arcing faults. Capacitors with a rating of, say, 50 kvar, will develop quite a heavily interrupting arc if fuses are extracted without first isolating the bank via the controlling device. The same will apply if the fuse is inserted while the continuity of the circuit is present.

6.6.7 Bus bar

The bus bar section of power factor panels shall withstand, as a minimum, the fault currents of the system at the point where it is intended to be connected. Usually, these panels are connected onto a section of the main installation where the fault currents are quite high.

If the manufacturer specifies a current-limiting device at the connection point of the equipment, the withstand test shall be carried out with this type of device connected in the circuit.

6.6.8 Connection of Systems

The bus bar system in these panels shall be arranged so that cables or bus bars to be connected and extended to the installation have sufficient area for take-off. If cables are used for this extension, they are usually of a large cross-sectional area and shall be of a suitable size to take the required rated current and fault current of the system.

7 SERVICE CONDITIONS

7.1 Normal Service Conditions

Panels conforming to this standard are intended for use under the normal service conditions detailed below.

NOTE — If components, for example relays, electronic equipment, are used which are not designed for these conditions, appropriate steps should be taken to ensure proper operation.

7.1.1 Ambient Air Temperature

7.1.1.1 Ambient air temperature for indoor installations

The ambient air temperature shall not exceed +40°C and its average over a period of 24 h shall not exceed +35°C.

The lower limit of the ambient air temperature shall be -5°C.

7.1.1.2 Ambient air temperature for outdoor installations

The ambient air temperature shall not exceed +50°C and its average over a period of 24 h shall not exceed +40°C.

The lower limit of the ambient air temperature shall be -25°C.

7.1.2 Atmospheric Conditions

7.1.2.1 Atmospheric conditions for indoor installations

The air shall be clean and its relative humidity shall not exceed 50 % at a maximum temperature of +40°C. Higher relative humidity may be permitted at lower temperatures, for example 90 % at +20°C. Moderate condensation should be borne in mind which may occasionally occur due to variations in temperature.

7.1.2.2 Atmospheric conditions for outdoor installations

The relative humidity may temporarily be as high as 100 % at a maximum temperature of +25°C.

7.1.3 Pollution Degree

The pollution degree refers to the environmental conditions for which the panel is intended.

For switching devices and components inside an enclosure, the pollution degree of the environmental conditions in the enclosure is applicable.

For the purpose of evaluating clearances and creepage distances, the following four degrees of pollution in the micro-environment are established.

Pollution degree 1: No pollution or only dry, non-conductive pollution occurs. The pollution has no influence.

Pollution degree 2: Only non-conductive pollution occurs except that occasionally a temporary conductivity caused by condensation is to be expected.

Pollution degree 3: Conductive pollution occurs or dry, non-conductive pollution occurs which is expected to become conductive due to condensation.

Pollution degree 4: Continuous conductivity occurs due to conductive dust, rain or other wet conditions.

Pollution degree 4 is not applicable for a micro-environment inside the panel to this standard.

Unless otherwise stated, panels for industrial applications are generally for use in a pollution degree-3 environment. However, other pollution degrees may be considered to apply, depending upon particular applications or the micro-environment.

NOTE — The pollution degree of the micro-environment for the equipment may be influenced by installation in an enclosure.

7.1.4 Altitude

The altitude of the site of installation does not exceed 2 000 m.

NOTE — For equipment to be used at higher altitudes, it is necessary to take into account the reduction of the dielectric strength, the switching capability of the devices and of the cooling effect of the air.

7.2 Special Service Conditions

Where any special service conditions exist, the applicable particular requirements shall be complied with or special agreements shall be made between the panel manufacturer and the user. The user shall inform the panel manufacturer if such exceptional service conditions exist.

Special service conditions include, for example:

- a) Values of temperature, relative humidity and/or altitude differing from those specified in 7.1
- b) Applications where variations in temperature and/or air pressure take place at such a speed that exceptional condensation is liable to occur inside the panel;
- c) Heavy pollution of the air by dust, smoke, corrosive or radioactive particles, vapours or salt;
- d) Exposure to strong electric or magnetic fields;
- e) Exposure to extreme climatic conditions;
- f) Attack by fungus or small creatures;
- g) Installation in locations where fire or explosion hazards exist;
- h) Exposure to heavy vibration and shocks;
- i) Installation in such a manner that the current-carrying capacity or breaking capacity is affected, for example equipment built into machines or recessed into walls;
- j) Consideration to appropriate remedies against conducted and radiated disturbances other than EMC.

- k) Consideration to appropriate remedies against EMC disturbances in environments other than those described in 8.

For installation in a place where the ambient temperature can be outside the normal service condition range stated in 7.1, the preferred ranges of minimum and maximum temperatures to be specified should be

- a) -50 °C and + 40°C for very cold climates
- b) -5°C and + 55°C for very hot climates

7.3 Conditions during Transport, Storage and Installation

A special agreement shall be made between the panel manufacturer and the user if the conditions during transport, storage and installation, for example temperature and humidity conditions, differ from those defined in 7.1.

8 ELECTROMAGNETIC COMPATIBILITY

The relevant clauses of the standards concerning capacitors (*see 2*) apply with the following additions.

8.1 Emission

Under normal service conditions, power capacitors do not produce any electromagnetic disturbance. Electromagnetic disturbances can only be generated by panels during switching operations (connection or disconnection of steps) and are limited to switching over voltages, the duration of which is measured in milliseconds. If the controller is regulated so as to limit the number of switching operations to not more than 5/min, the requirements of electromagnetic emission are deemed to be satisfied and no verification is necessary.

8.2 Immunity

Panels not incorporating electronic equipment are not sensitive to normal electromagnetic disturbances, and therefore no immunity tests are required.

8.3 Panels Incorporating Electronic Equipment

Electronic equipment (i.e. the controller) incorporated in panels shall comply with the immunity and emission requirements of the relevant Indian standard(s).

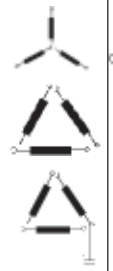
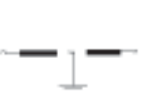
9 INFORMATION TO BE GIVEN WITH ENQUIRY OR ORDER

The following minimum information is recommended to be given at the stage of enquiry or order of APFC panels:

- a) Output, kvar
- b) Rated voltage, volts
- c) Rated frequency, Hz
- d) Number of phases
- e) Configuration for 3-phase panels: star or delta
- f) Number of stages of panel and kvar of each stage
- g) Type of switching, electro-mechanical or electronic
- h) Rated impulse withstand voltage (U_{imp})
- i) Short-circuit withstand strength, in amperes (kA)
- j) State whether any abnormal voltage rises are expected. If so, state highest voltage expected in the system of installation
- k) Type of capacitor: SH / NSH, MPP/ APP, dry type, oil filled
- l) Series reactor – Yes or No. If yes, % (0.1%, 0.2%, 0.5%, 1%, 5.67%, 7%, 14%) and conductor material - copper / aluminium
- m) Upper limit of temperature category
- n) Indoor or outdoor installation
- o) Proposed location of APFC panels:
 - i) Local substation (If so, state kVA rating of the transformer etc.,)
 - ii) Distribution circuit level
 - iii) Load (appliances, equipment level)
 - iv) Special application
 - v) Any other
- p) Altitude above sea level of installation location
- q) Degree of protection - IP Clause
- r) Tamperproof design – Yes or No
- s) Any special requirement that may affect the design or operation of the panel
- t) Reference to IS

Annex A
(Clauses 5.8.1.1 & 5.8.1.2)

CORRESPONDENCE BETWEEN THE NOMINAL VOLTAGE AT THE SUPPLY SYSTEM AND THE EQUIPMENT RATED IMPULSE WITHSTAND VOLTAGE

Sl. No.	Maximum value of rated operational voltage to earth, a.c .r.m.s. or d.c. V (2)	Nominal Voltage of the supply system ($\leq$ rated insulation voltage of the equipment) V (3)				Preferred values of rated impulse withstand voltage (1,2/50 μ s) at 1000 m kV (4)			
		 a.c .r.m.s.	 a.c .r.m.s	 a.c .r.m.s. or d.c	 a.c .r.m.s. or d.c	IV Origin of installation (service entrance level)	III Distribution circuit level	II Load (appliance, equipment) level	I Specially protected level
i	50	-	-	12,5,24,25,30,42,48	-	1,5	0,8	0,5	0,33
ii	100	66/115	66	60	-	2,5	1,5	0,8	0,5
iii	150	120/208 127/220	115,120 127	110,120	220-110, 240-120	4	2,5	1,5	0,8
iv	300	220/380, 230/400 240/415, 260/440 277/480	220,230 240,260 277	220	440-220	6	4	2,5	1,5
v	600	347/600, 380/660 400/690, 415/720 480/830	347,380, 400 415,440, 480 500,577,	480	960-480	8	6	4	2,5
vi	1000	-	600 660 690,720 830,1000	1000	-	12	8	6	4

Annex B
(Clause 5.9.2)

GUIDELINES FOR SELECTION OF CROSS SECTION OF EXTERNAL TEST CONDUCTORS FOR TEMPERATURE RISE TEST BASED ON THE TEST CURRENT

Table B.1 – Copper Conductors for Rated Current up to 400 A Inclusive

Sl No. (1)	Range of Rated Current ^a A (2)		Conductor Cross-sectional Area ^{b,c} (3)	
			mm ²	AWG/MCM
i)	0	8	1.0	18
ii)	8	12	1.5	16
iii)	12	15	2.5	14
iv)	15	20	2.5	12
v)	20	25	4.0	10
vi)	25	32	6.0	10
vii)	32	50	10	8
viii)	50	65	16	6
ix)	65	85	25	4
x)	85	100	35	3
xi)	100	115	35	2
xii)	115	130	50	1
xiii)	130	150	50	0
xiv)	150	175	70	00
xv)	175	200	95	000
xvi)	200	225	95	0000
xvii)	225	250	120	250
xviii)	250	275	150	300
xix)	275	300	185	350
xx)	300	350	185	400
xxi)	350	400	240	500

^a The value of the rated current shall be greater than the first value in the first column and less than or equal to the second value in that column.

^b For convenience of testing and with the manufacturer's consent, smaller test conductors than those given for a stated rated current may be used.

^c Either of the two conductors specified may be used.

NOTE—

The minimum length of each temporary connection from terminal to test supply shall be

- a) 1 m for cross section up to and including **35 mm²**
- b) 2 m for cross section larger than **35 mm²**

Table B.2 — Copper Conductors for Rated Current from 400 A to 4000 A

Sl No.	Range of rated current ^a	Test Conductors			
		Quantity	Cables Cross-sectional Area mm ²	Quantity	Copper bars ^b Dimensions mm (W × D)
i)	400 to 500	2	150	2	30 × 5
ii)	500 to 630	2	185	2	40 × 5
iii)	630 to 800	2	240	2	50 × 5
iv)	800 to 1 000			2	60 × 5
v)	1 000 to 1 250			2	80 × 5
vi)	1 250 to 1 600			2	100 × 5
vii)	1 600 to 2 000			3	100 × 5
viii)	2 000 to 2 500			4	100 × 5
ix)	2 500 to 3 150			3	100 × 10
x)	3 150 to 4 000			4	100 × 10

^a The value of the rated current shall be greater than the first value and less than or equal to the second value.

^b Bars are assumed to be arranged with their long faces (W) vertical. Arrangements with long faces horizontal may be used if specified by the manufacturer. Bars may be painted.

NOTE—

The minimum length of each temporary connection from terminal to test supply shall be

- 2 m for test current up to 800 A
- 3 m for test current above 800 A and up to 4000 A. This can be reduced to 2m provided that the temperature rise at the supply end of the connection is not more than 5 K below the temperature rise in the middle of the connection length.

Table B.3 — Cross section of Aluminium Conductors for Values of Test Current up to 400 A Inclusive

Sl. No.	Range of Test (2) Current (A)	AC Conductor Size mm ²
i)	0-8	1.5
ii)	8-12	1.5
iii)	12-15	2.5
iv)	15-20	4.0
v)	20-25	6
vi)	25-32	10
vii)	32-50	16
viii)	50-65	25
ix)	65-85	35
x)	85-100	50
xi)	100-115	50
xii)	115-130	70
xiii)	130-150	70
xiv)	150-175	95
xv)	175-200	150
xvi)	200-225	150
xvii)	225-250	185
xviii)	250-275	240
xix)	275-300	240
xx)	300-350	240
xxi)	350-400	300

NOTES

1. Connections shall be single core, PVC insulated, aluminium cables or wires as indicated.

2. For single phase or multiphase tests the minimum length of each temporary connections from terminal to terminal or to the test supply or to a star point shall be:

- 1 m for cross section up to and including 50 mm²
- 2 m for cross section larger than 50 mm²

Table B.4 — Cross Section of Aluminium Conductors for Values of Test Current Higher than 400 A

Sl No. (1)	Range of Test Current (2)	Aluminium Bars (3)	
	(A)	Quantity	Dimensions mm (W × D)
i)	400-500	2	32 × 8
ii)	500-630	2	40 × 8
iii)	630-800	2	50 × 8
iv)	800-1000	2	50 × 10
v)	1000-1250	2	63 × 12
vi)	1250-1600	4	50 × 8
vii)	1600-2000	3	100 × 10
viii)	2000-2500	4	100 × 10
ix)	2500-3150	4	150 × 10

NOTES

- The connections shall be made with matt black finished aluminium bars
- The minimum length of each temporary connection from terminal to terminal shall be 2 m.

Annex C
EXAMPLES OF SWITCHING SEQUENCE FOR APFC PANEL
(Clause 5.15.2)

Example 1: Single stage switching

APFC panel: 75 kvar of 7 stages with stage size: 6.25, 6.25, 12.5, 12.5, 12.5, 12.5, 12.5

Switching sequence: (6.25-6.25-12.5-12.5-12.5-12.5-12.5)

SI No.	Panel Stage(s) to be Switched ON (Q _s)	Inductive Load (Q _L) ^{a)}	APFC Panel Stage(s) Automatically Switched ON (Q _c)	Total Size of Capacitor Stages Switched ON (kvar)	(Q _L – Q _c)	(Q _L – Q _s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	6.25	10	6.25	6.25	3.75	3.75
ii)	6.25	5 + 3.75	6.25	12.5	2.5	2.5
iii)	12.5	10	12.5	25	0	0
iv)	12.5	15	12.5	37.5	2.5	2.5
v)	12.5	10 + 2.5	12.5	50	0	0
vi)	12.5	15	12.5	62.5	2.5	2.5
vii)	12.5	10 + 2.5	12.5	75	0	0

^{a)}Q_L shall be either equal to or greater than the stage size (s) of the panel to be switched, however, shall not exceed the size of the next higher stage.

Example 2: Single and multiple stage switching

APFC panel: 100 kvar of 5 stages with stage size: 5, 5, 15, 25, 50

Switching sequence: (25-50-5-5-15)

SI No.	Panel Stage(s) to be Switched ON (Q _s)	Inductive Load (Q _L) ^{a)}	APFC Panel Stage(s) Automatically Switched ON (Q _c)	Total Size of Capacitor Stages Switched ON (kvar)	(Q _L – Q _c)	(Q _L – Q _s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	25	25	25	25	0	0
ii)	50	50	50	75	0	0
iii)	5-5-15	25	5 + 5 + 15	100	0	0

^{a)}Q_L shall be either equal to or greater than the stage size (s) of the panel to be switched, however, shall not exceed the size of the next higher stage.

Example 3: One step switching of all stages

APFC panel: 100 kvar of 5 stages with stage size: 5, 5, 15, 25, 50

Switching sequence: (15-25-50-5-5)

SI No.	Panel Stage(s) to be Switched ON (Q _s)	Inductive Load (Q _L) ^{a)}	APFC Panel Stage(s) Automatically Switched ON (Q _c)	Total Size of Capacitor Stages Switched ON (kvar)	(Q _L – Q _c)	(Q _L – Q _s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	15-25-50-5-5	120	15+ 25 + 50 + 5 + 5	100	20	20

^{a)}Q_L shall be either equal to or greater than the stage size (s) of the panel to be switched, however, shall not exceed the size of the next higher stage.

Example 4: Single and multiple stage switching
 APFC panel: 450 kvar of 8 stages with stage size: 25, 25, 25, 75, 75, 75, 75, 75.
 Switching sequence: (25-25-25-75-75-75-75-75)

Sl No.	Panel Stage(s) to be Switched ON (Qs)	Inductive Load (Q _L) ^{a)}	APFC Panel Stage(s) Automatically Switched ON (Q _C)	Total Size of Capacitor Stages Switched ON (kvar)	(Q _L – Q _C)	(Q _L – Q _s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
i)	25	25	25	25	0	0
ii)	25	50	25 + 25	75	0	0
iii)	25	100	75	150	25	25
iv)	75	50	75	225	0	0
v)	75	100	75	300	25	25
vi)	75	50	75	375	0	0
vii)	75	100	75	450	25	25

^{a)}Q_L shall be either equal to or greater than the stage size (s) of the panel to be switched, however, shall not exceed the size of the next higher stage.

ANNEX D

(Clauses 5.16.1, 6.3.8 & 6.5.5)

FORMULAE FOR APFC PANEL INSTALLATIONS

(Informative)

D-1 RESONANCE FREQUENCY

A capacitor will be in resonance with a harmonic in accordance with the following equation in which n is an integer:

$$n = \sqrt{\frac{S}{Q}}$$

where,

- S is the short-circuit power (MVA) where the capacitor is to be installed;
- Q is expressed in megavars (Mvar);
- n is the harmonic number: that is, the ratio between the resonant harmonic (Hz) and the network frequency (Hz).

D-2 VOLTAGE RISE

Connection of a shunt capacitor will cause the steady-state voltage to rise, given by the following expression:

$$\frac{\Delta U}{U} \approx \frac{Q}{S}$$

where,

- ΔU is the voltage rise in volts (V);
- U is the voltage before connection of the capacitor (V);
- S is the short-circuit power (MVA) where the capacitor is to be installed;
- Q is expressed in megavars (Mvar).

D-3 INRUSH TRANSIENT CURRENT

D-3.1 Switching In of a Single Capacitor

$$\hat{I}_s \approx I_N \sqrt{\frac{2S}{Q}}$$

Where

- $\hat{I}_s$ is the peak of inrush capacitor current in amperes (A);
- I_N is the rated capacitor current (r.m.s.) in amperes (A);
- S is the short-circuit power (MVA) where the capacitor is to be installed;
- Q is expressed in megavars (Mvar).

D-3.2 switching of Capacitors in Parallel with Energized Capacitor(s)

$$\hat{I}_s = \frac{U\sqrt{2}}{\sqrt{X_c X_L}}$$

$$f_s = f_N \sqrt{\frac{X_c}{X_L}}$$

where

- $\hat{I}_s$ is the peak of inrush capacitor current in amperes (A);
- U is the phase-to-earth voltage in volts (V);
- X_c is the series-connected capacitive reactance per phase in ohms (Ω);

IS 16636 : 2017

- X_L is the inductive reactance per phase between the banks in ohms (Ω);
 f_s is the frequency of the inrush current in hertz (Hz);
 f_N is the rated frequency in hertz (Hz).

D-3.3 Discharge Resistance In Single-Phase Units Or In One-Phase Or Polyphase Units

$$R \leq \frac{t}{\left[kC \ln \left(\frac{U_N \sqrt{2}}{U_R} \right) \right]}$$

where

- t is the time for discharge from $U_N \sqrt{2}$ to U_R in seconds (s);
 R is the discharge resistance in megohms ($M\Omega$);

- C is the rated capacitance per phase in microfarads (μF);
 U_N is the rated voltage of unit in volts (V);
 U_R is the permissible residual voltage in volts (V) (see IS 13340 / IEC 60831-1 and IS 13585 / IEC 60931-1 for limits of t and U_R);
 K is the coefficient depending on the method of connection of the resistors to the capacitor units (see IS 13340 / IEC 60831-1 and IS 13585 / IEC 60931-1).

Annex E (Clause 6.4) (Informative)

MEASUREMENT OF RESPONSE TIME OF THE PANEL FOR PF CORRECTION

Response time can be measured along with the test at 5.15 for "Verification of effectiveness of automatic PF correction".

For measuring the response time, mains current (I_M), inductive current (I_L) and capacitor current (I_C) are to be measured, simultaneously, on a common time scale, as indicated in Fig. E1.

Step 1) to Step 5) shall be same as of 5.15.2.

Step 6): Mains current (I_M), inductive current (I_L) and capacitor current (I_C) are measured, simultaneously, on a common time scale.

Step 7): Inductive load switched, panel stages automatically switched and the interval of time between the instant of sensing the inductive load current and the instant of achieving the lowest mains current are noted down for individual and / or multiple stages of switching, as schematically shown in Fig. E2.

The observations to be reported as follows:

Inductive load switched ON (Q_L)	Capacitor bank(s) automatically switched (Q_C)	Measured response time

Suitable oscilloscope (of bandwidth 100 kHz, minimum) and current probes with appropriate response characteristics like frequency band & current amplitude depending on the rating of the panel may be employed for measuring response time.

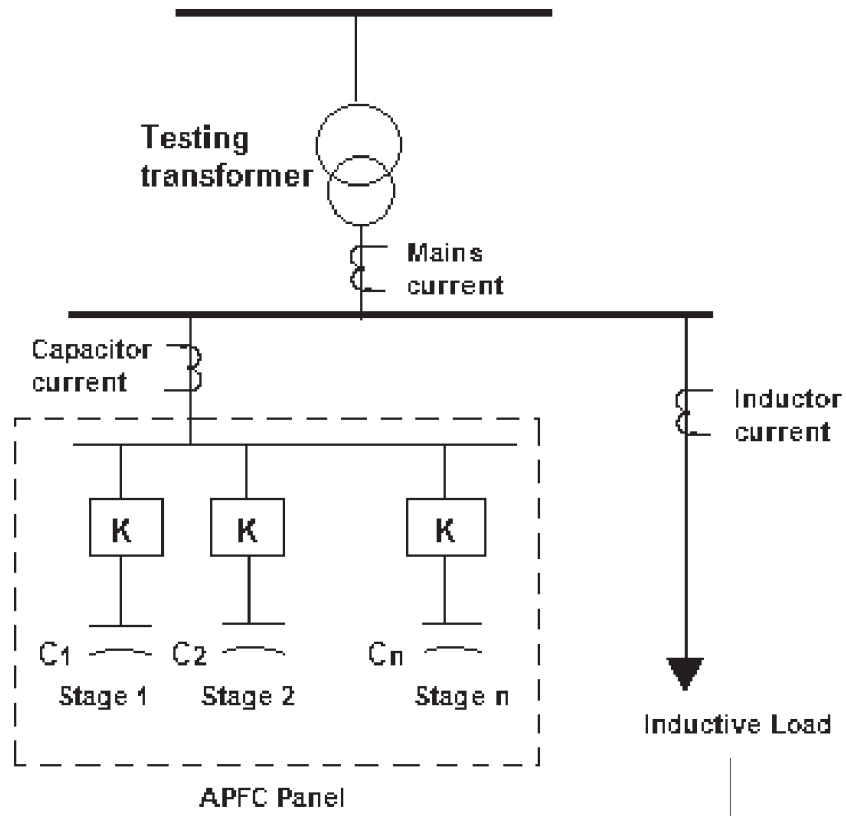
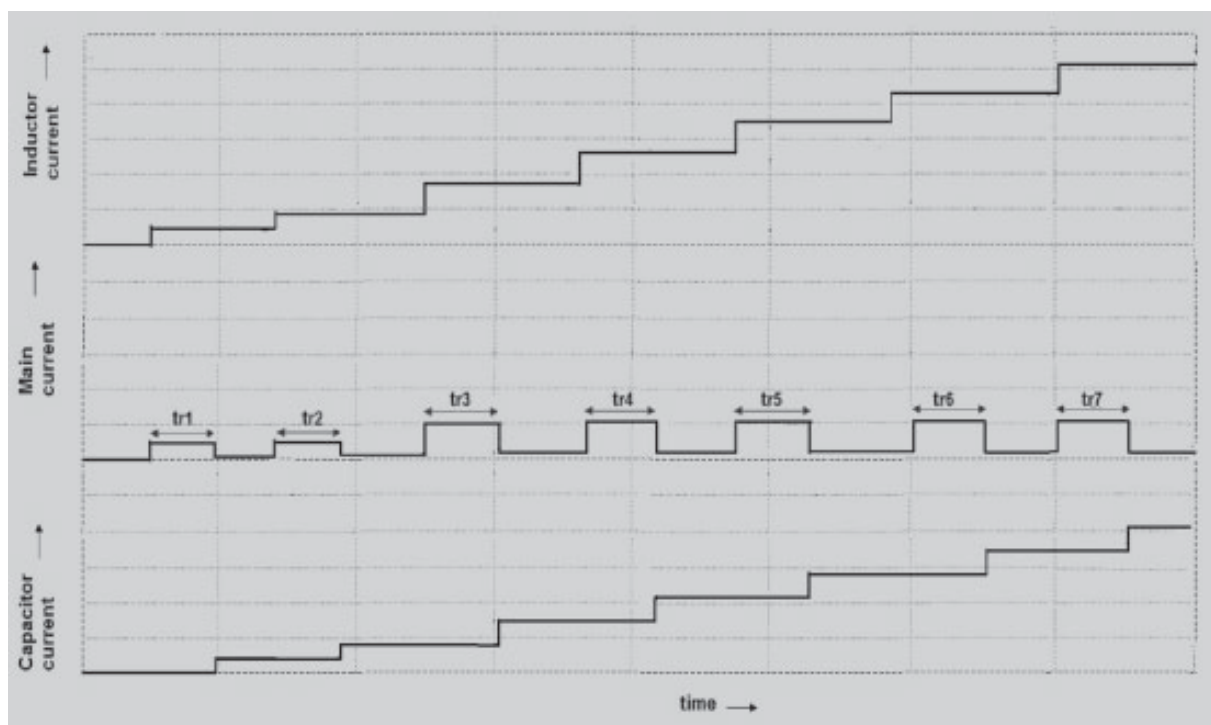
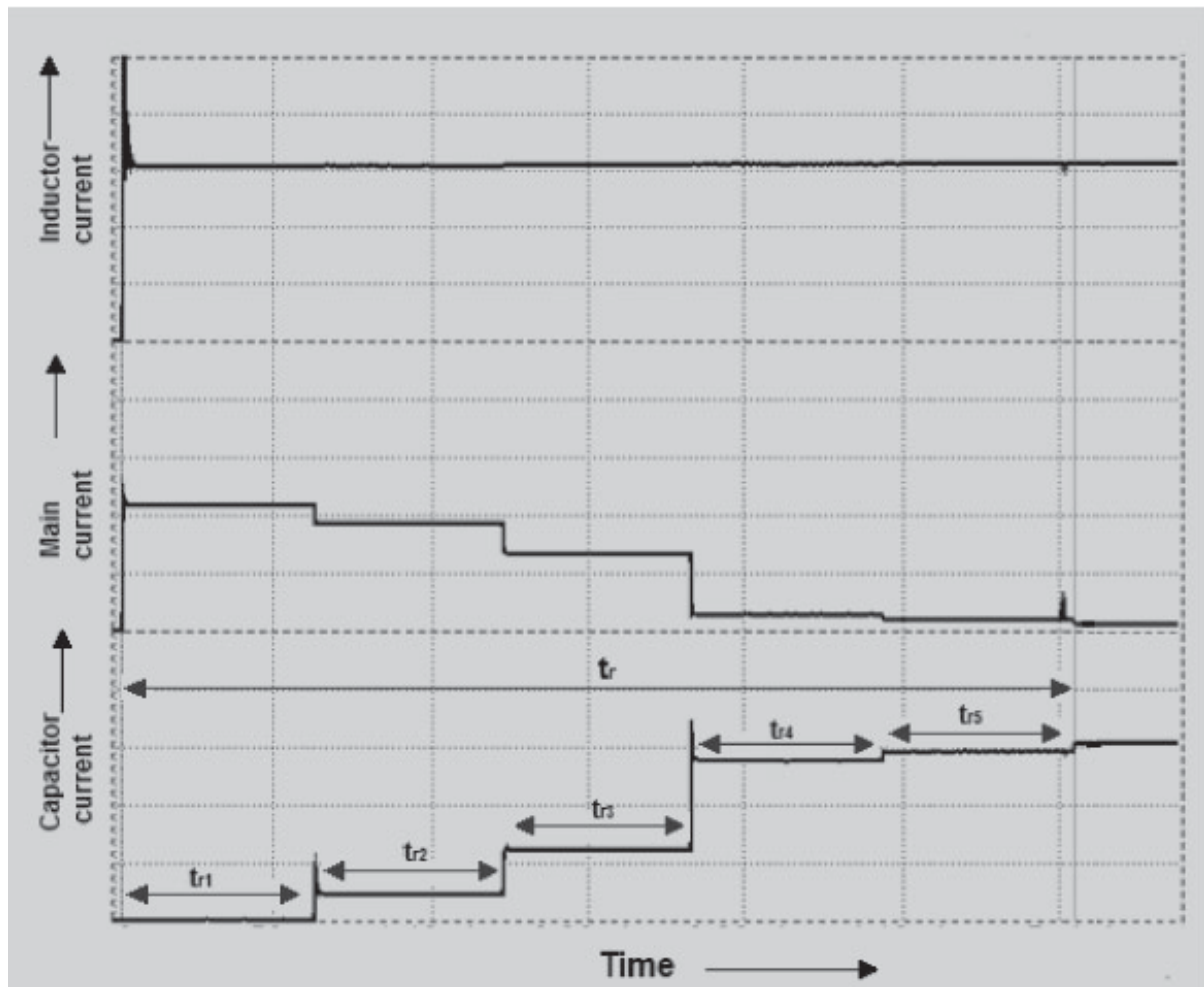


FIG. E1 ARRANGEMENT FOR MEASURING MAINS CURRENT, INDUCTIVE CURRENT AND CAPACITIVE CURRENT FOR RESPONSE TIME MEASUREMENT



(a) Response time measured for a 7 stage APFC panel – Sequential switching of individual stages (refer to Example 1 at Annex C)



(b) Response time measured for a 5 stage APFC panel - One step switching of all stages (refer to Example 3 at Annex C)

Fig. E2 Response Time of APFC Panel

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standards Act*, 1986 to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Copyright

BIS has the copyright of all its publications. No part of these publications may be reproduced in any form without the prior permission in writing of BIS. This does not preclude the free use, in course of implementing the standard, of necessary details, such as symbols and sizes, type or grade designations. Enquiries relating to copyright be addressed to the Director (Publications), BIS.

Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the latest issue of 'BIS Catalogue' and 'Standards: Monthly Additions'.

This Indian Standard has been developed from Doc No.: ETD 29 (10378).

Amendments Issued Since Publication

Amendment No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002

Telephones: 2323 0131, 2323 3375, 2323 9402

Website: www.bis.org.in

Regional Offices:

Telephones

Central	: Manak Bhavan, 9 Bahadur Shah Zafar Marg NEW DELHI 110002	{ 2323 7617 2323 3841
Eastern	: 1/14, C.I.T. Scheme VII M, V.I.P. Road, Kankurgachi KOLKATA 700054	{ 2337 8499, 2337 8561 2337 8626, 2337 9120
Northern	: SCO 335-336, Sector 34-A, CHANDIGARH 160022	{ 260 3843 260 9285
Southern	: C.I.T. Campus, IV Cross Road, CHENNAI 600113	{ 2254 1216, 2254 1442 2254 2519, 2254 2315
Western	: Manakalaya, E9 MIDC, Marol, Andheri (East) MUMBAI 400093	{ 2832 9295, 2832 7858 2832 7891, 2832 7892

Branches : AHMEDABAD. BENGALURU. BHOPAL. BHUBANESHWAR. COIMBATORE. DEHRADUN. FARIDABAD. GHAZIABAD. GUWAHATI. HYDERABAD. JAIPUR. KOCHI. LUCKNOW. NAGPUR. PARWANOO. PATNA. PUNE. RAJKOT. VISAKHAPATNAM.